Overview of the Experiment

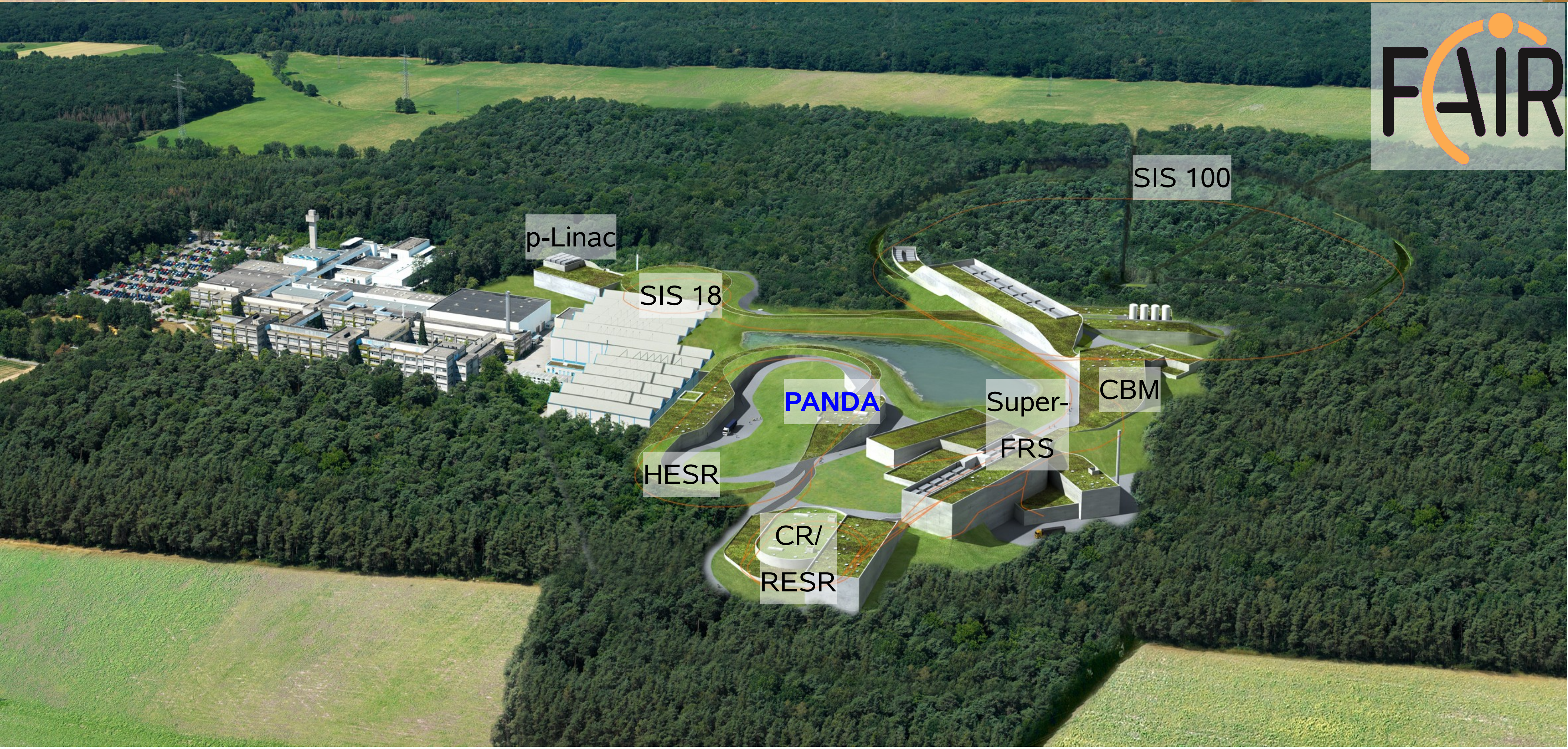
BNL – GSI Meeting, Brookhaven National Laboratory, November 21st - 22nd 2011

Lars Schmitt, GSI Darmstadt

- Antiprotons at FAIR
- PANDA Physics and Spectrometer

  Highlights: GEM Tracker, DIRC, PWO Calorimeter
- Cooperation Topics

Facility for Antiproton and Ion Research



New facility featuring:

Rare isotope beams, heavy ion beams, anti-protons

→ Optimal usage of accelerator facilities

Layout of the Facility

Primary beams

- U up to 35 AGeV
- Protons up to 30 GeV/c
- 100-1000x more

Secondary beams

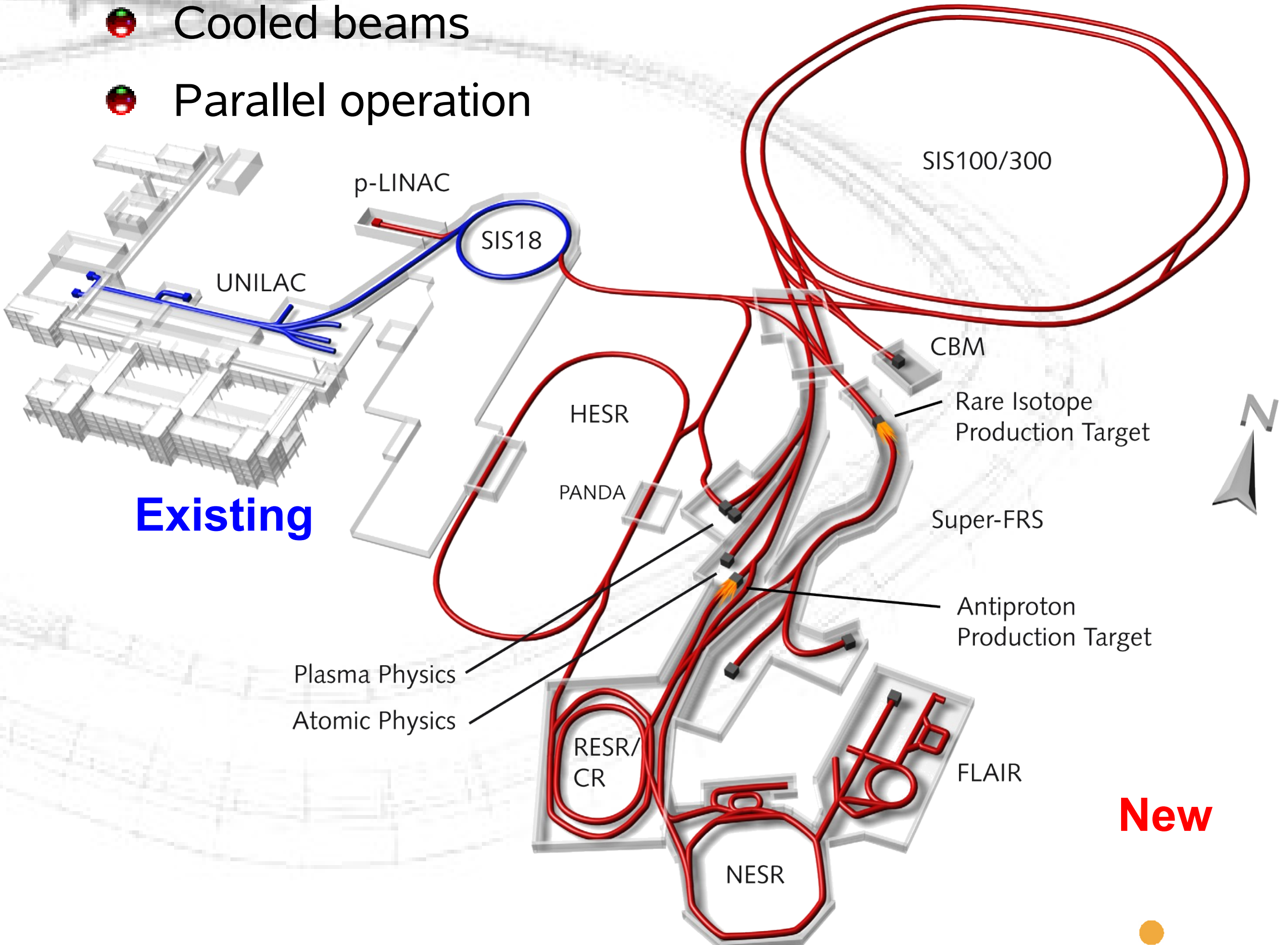
- Broad range of rare isotopes, 10000x more
- $\bar{p}$: 0-15 GeV/c

Storage and cooler rings

- Radioactive beams
- e^-- A (or $\bar{p}$ - A) collider
- Antiprotons

Key features

- Rapidly cycling SC magnets
- Cooled beams
- Parallel operation



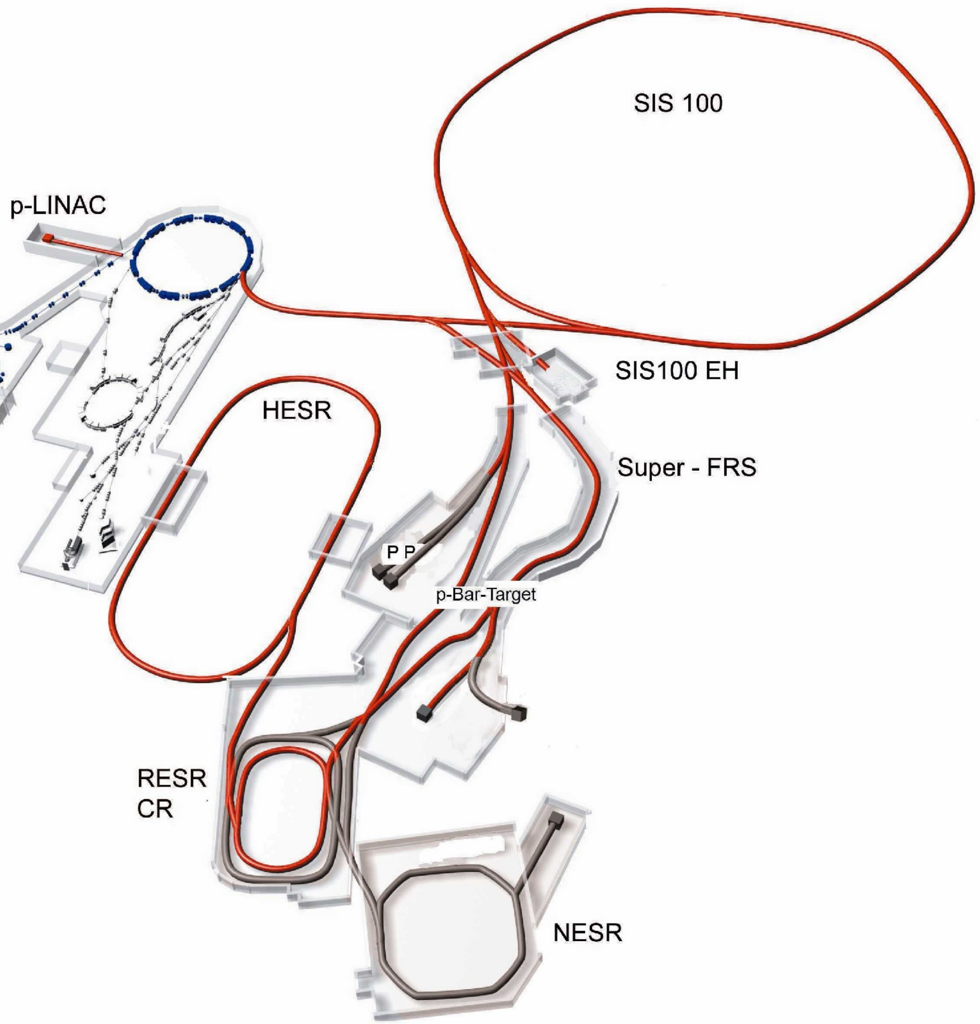
Antiprotons at FAIR

Antiproton production

- Proton Linac 70 MeV
- Accelerate p in SIS18 / 100
- Produce $\bar{p}$ on Cu target
- Collection in CR, fast cooling
- Accumulation in RESR, slow cooling
- Storage in HESR and usage in PANDA

Modularised Start Version

- RESR is postponed (Mod. 4)
- Accumulation in HESR
- 10x lower luminosity



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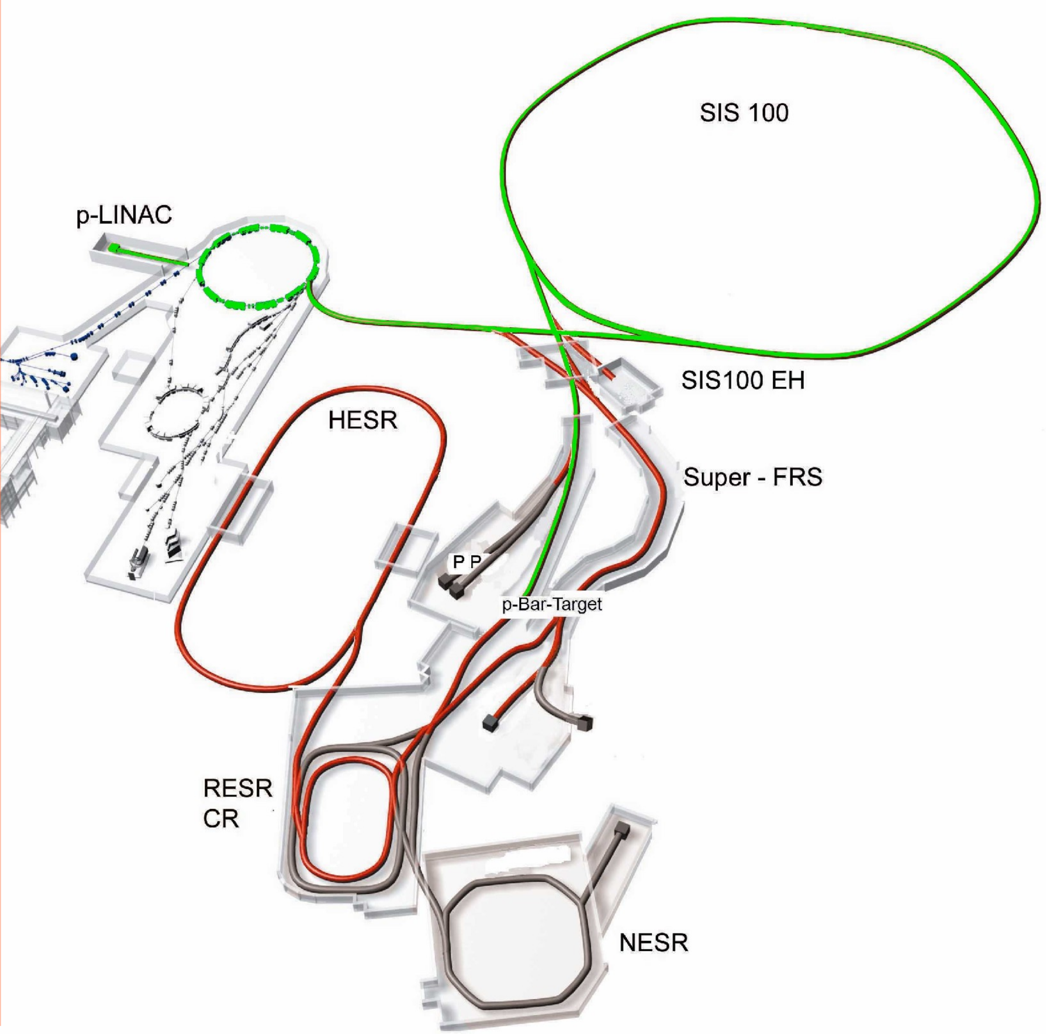

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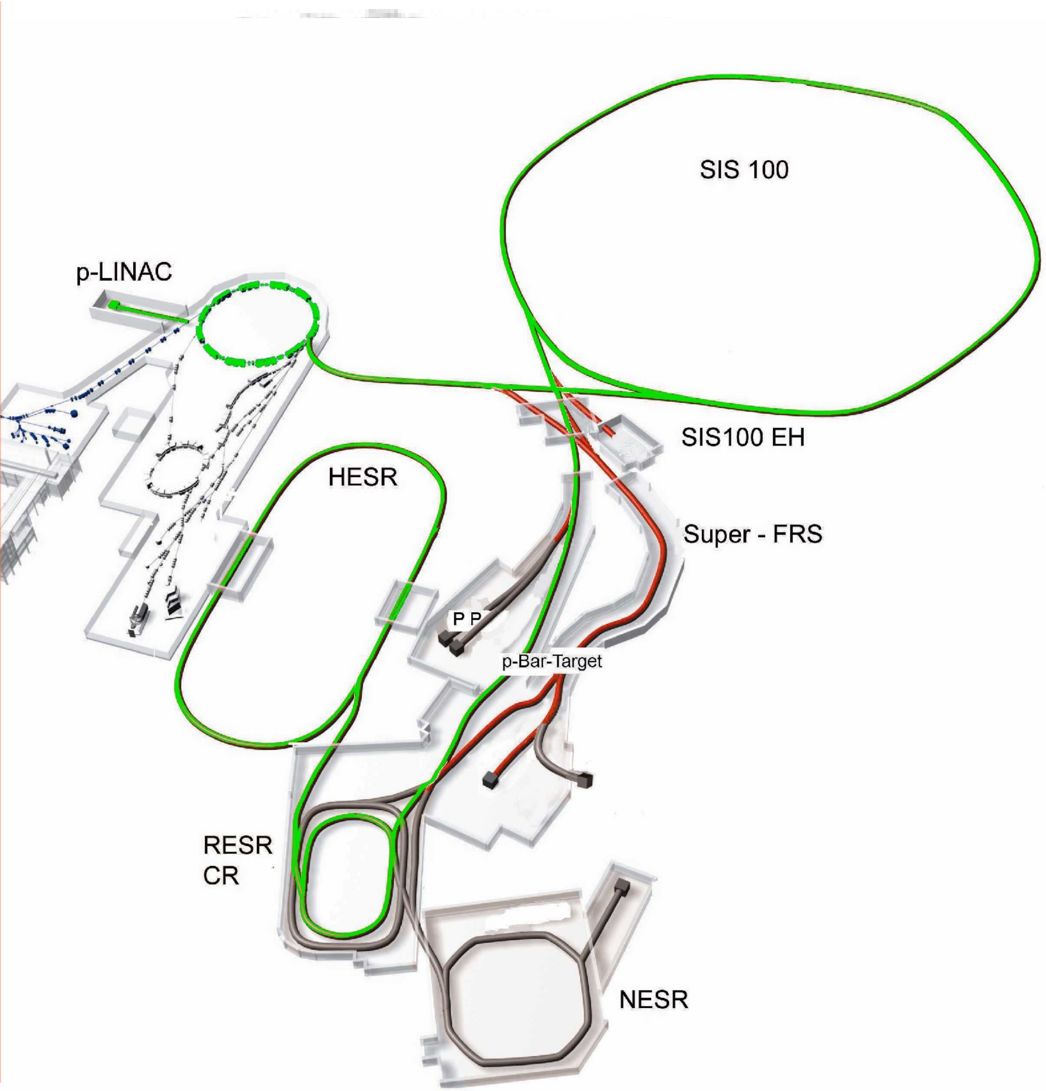
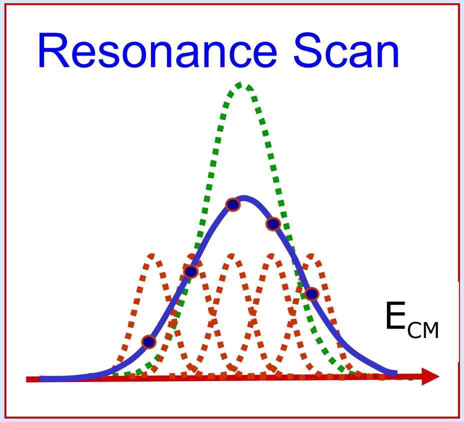


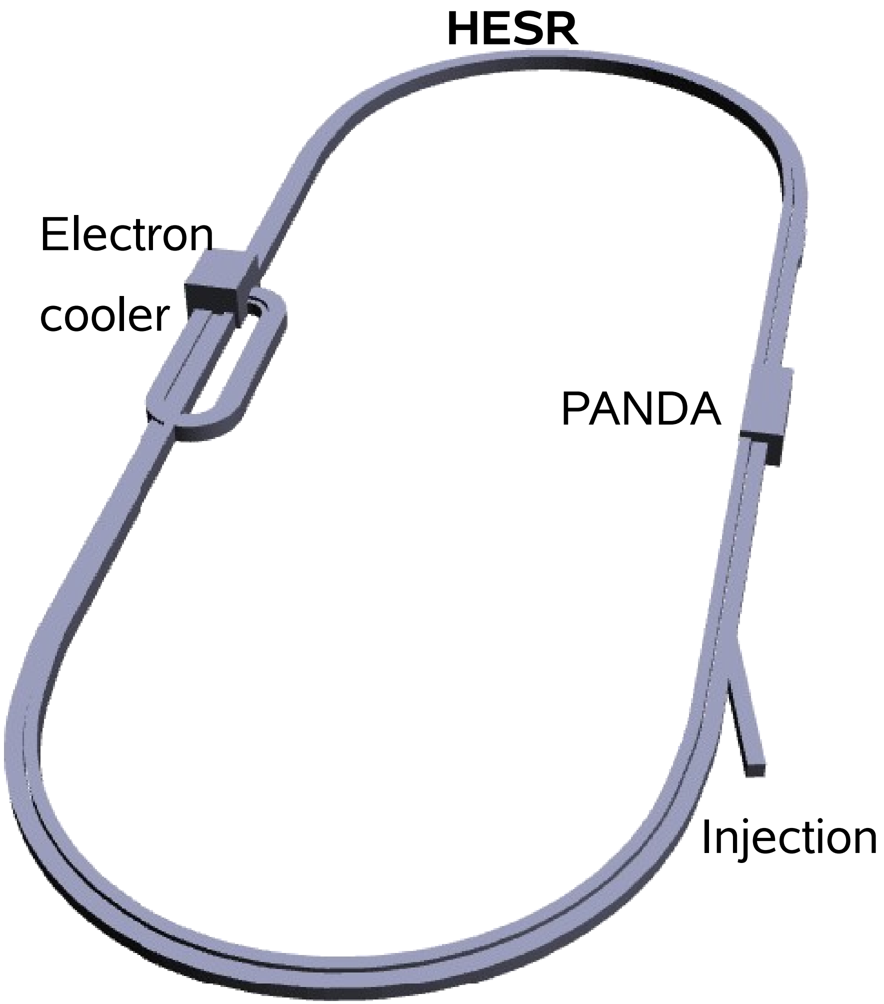
High Energy Storage Ring

HESR Parameters

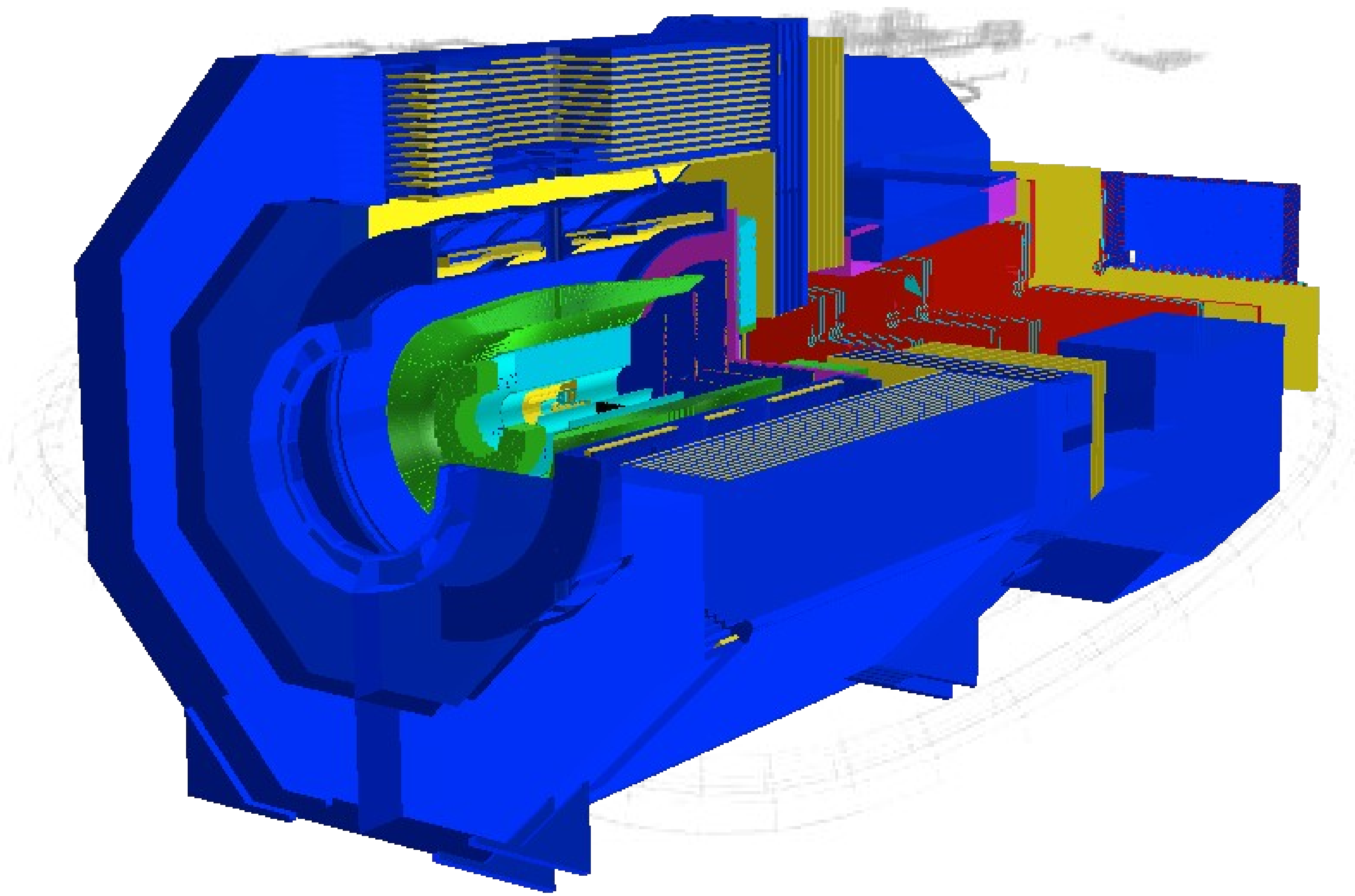
- Storage ring for internal target
- Initially also used for accumulation
- Injection of $\bar{p}$ at 3.7 GeV/c
- Slow synchrotron (1.5-15 GeV/c)
- Luminosity up to L~ $2x10^{32}$ $cm^{-2}s^{-1}$

- Stochastic & electron cooling
- Energy resolution ~50 keV
- Tune E_{CM} to probe resonance
- Get precise m and Γ





The PANDA Experiment at FAIR



Physics Goals of $\overline{\mathrm{P}}$ANDA

Hadron Spectroscopy

Experimental Goals: *mass, width & quantum numbers J^{PC} of resonances*

Charm Hadrons: *charmonia, D-mesons, charm baryons*

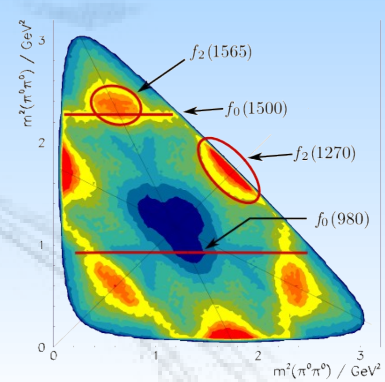
➔ Understand new XYZ states, $D_s(2317)$ and others

Exotic QCD States: *glueballs, hybrids, multi-quarks*

Spectroscopy with Antiprotons:

Production of states of all quantum numbers

Resonance scanning with high resolution



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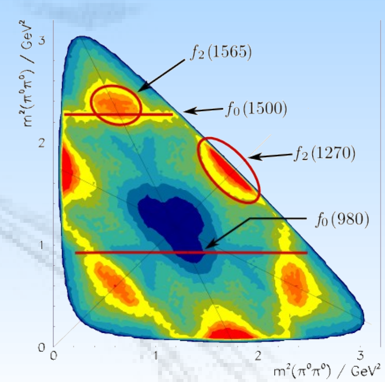

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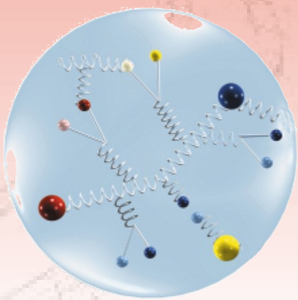
Hadron Structure

Generalized Parton Distributions

➔ Formfactors and structure functions, L_q



Timelike Nucleon Formfactors

Drell-Yan Process

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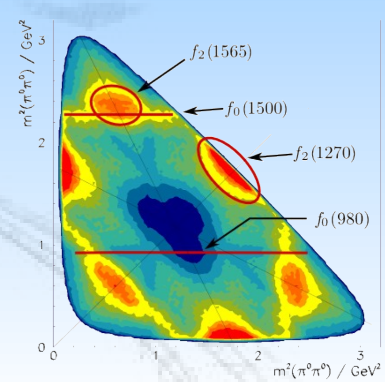

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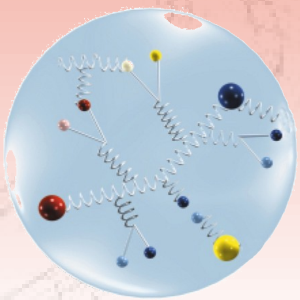
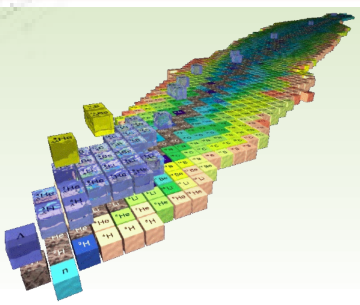


Nuclear Physics

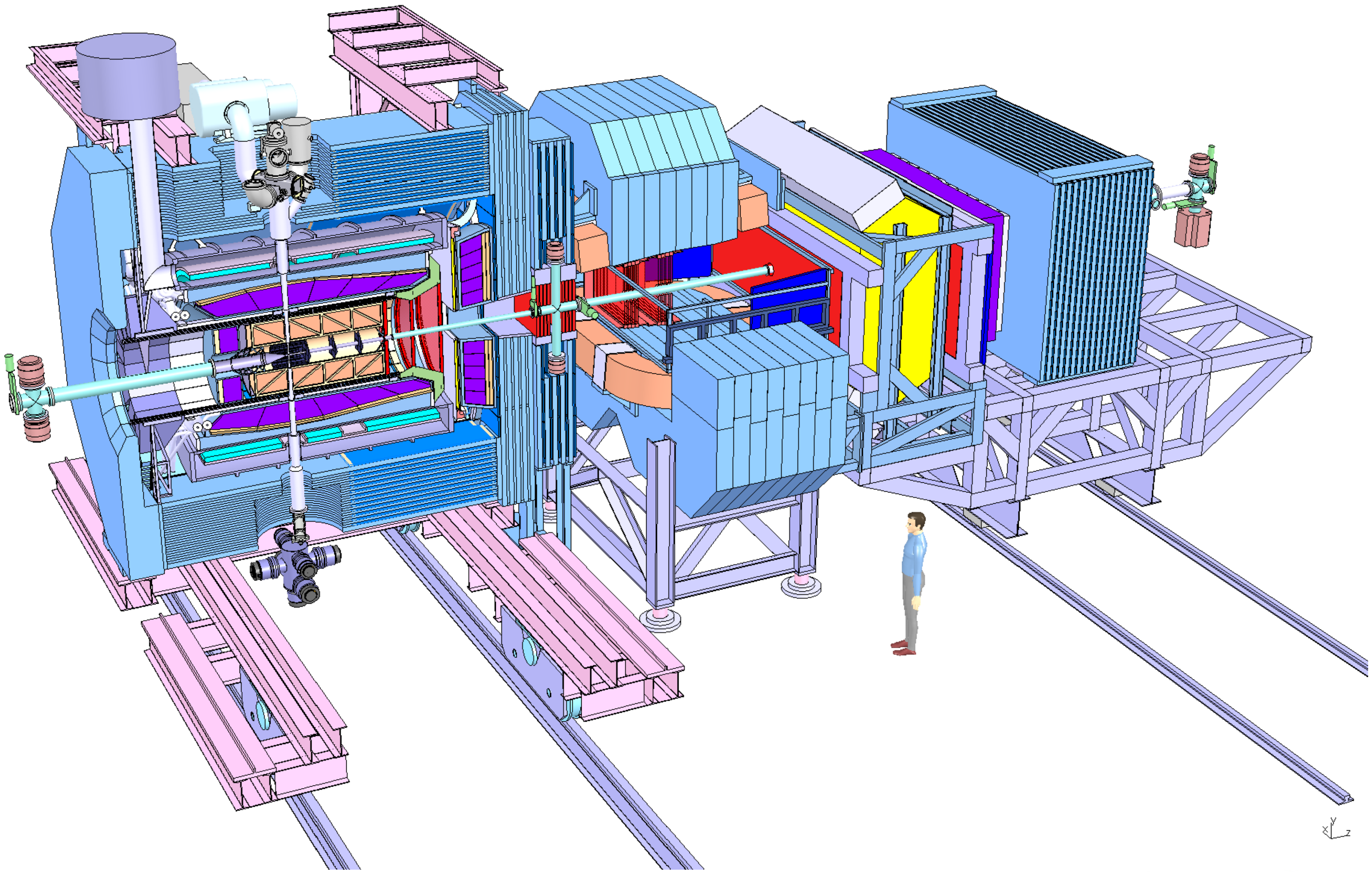
***Hypernuclei**:* Production of double Λ-hypernuclei

➔ γ-spectroscopy of hypernuclei, YY interaction

Hadrons in Nuclear Medium



PANDA Spectrometer



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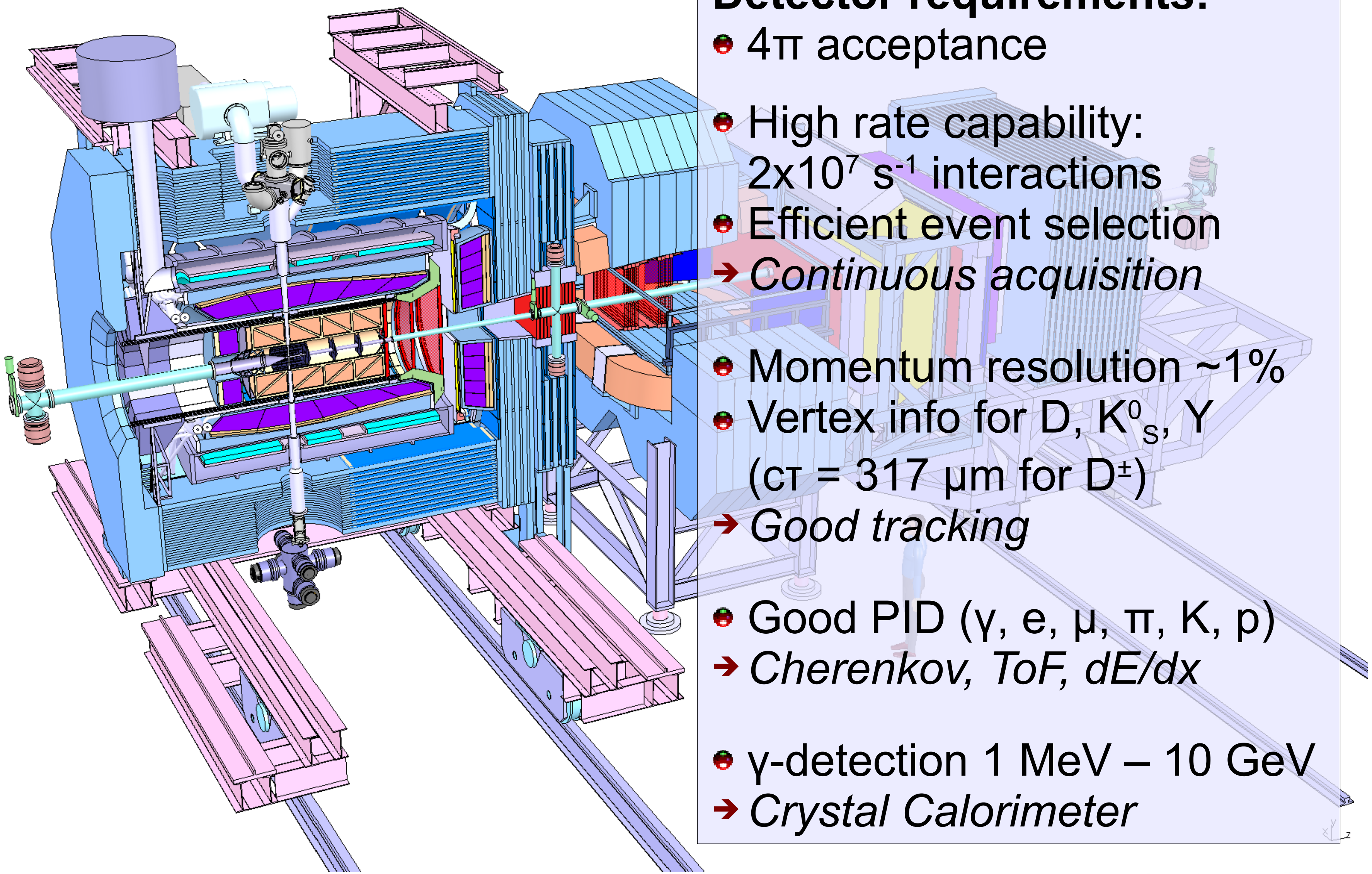

Detector requirements:

- 4π acceptance
- High rate capability: $2\times10^{7}\ s^{-1}$ interactions
- Efficient event selection
- ➔ *Continuous acquisition*
- Momentum resolution ~1%
- Vertex info for D, K^0_S, Y ($c\tau$ = 317 μm for $D^{\pm}$)
- ➔ *Good tracking*
- Good PID (γ, e, μ, π, K, p)
- ➔ *Cherenkov, ToF, dE/dx*
- γ-detection 1 MeV – 10 GeV
- ➔ *Crystal Calorimeter*

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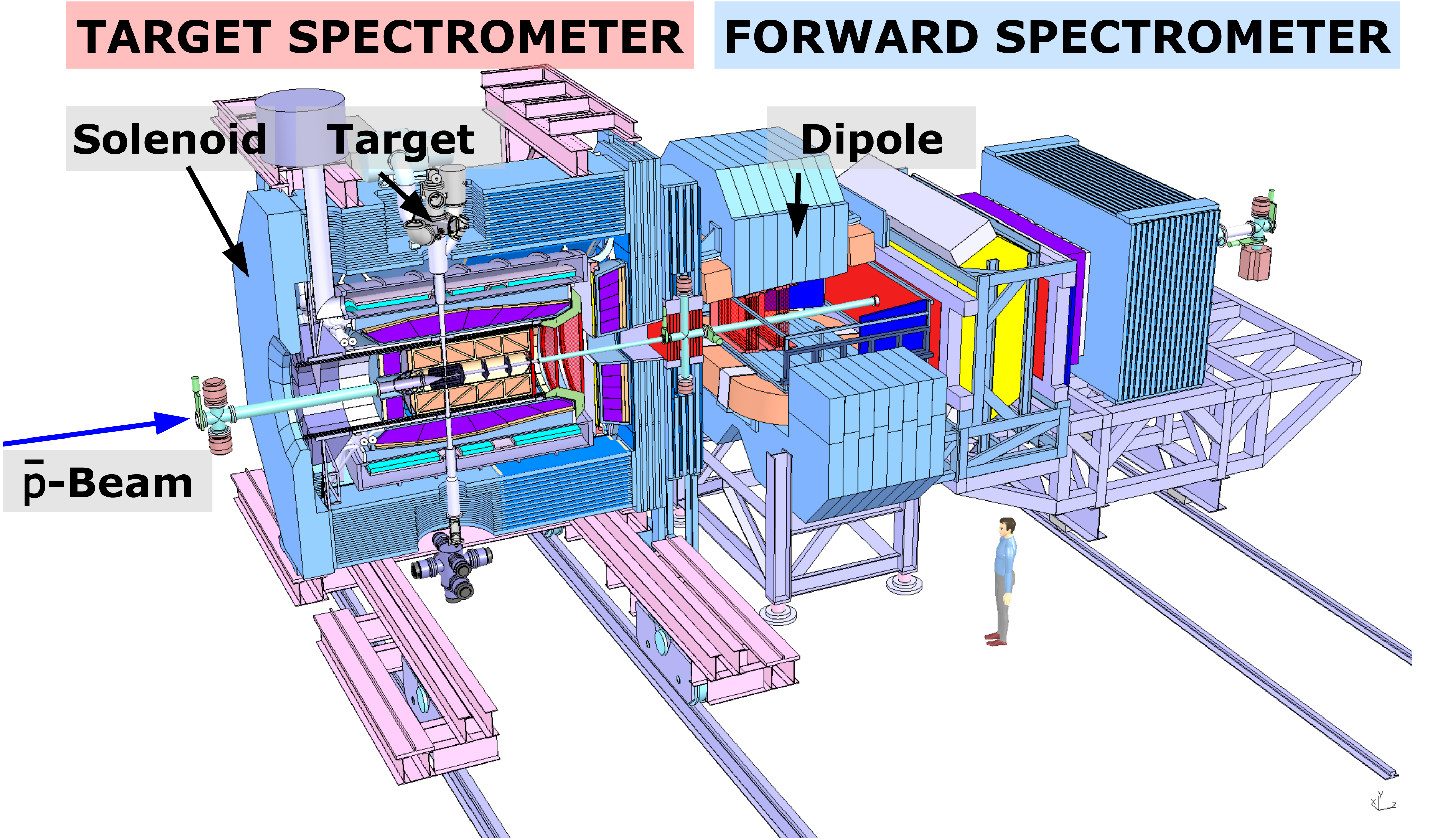

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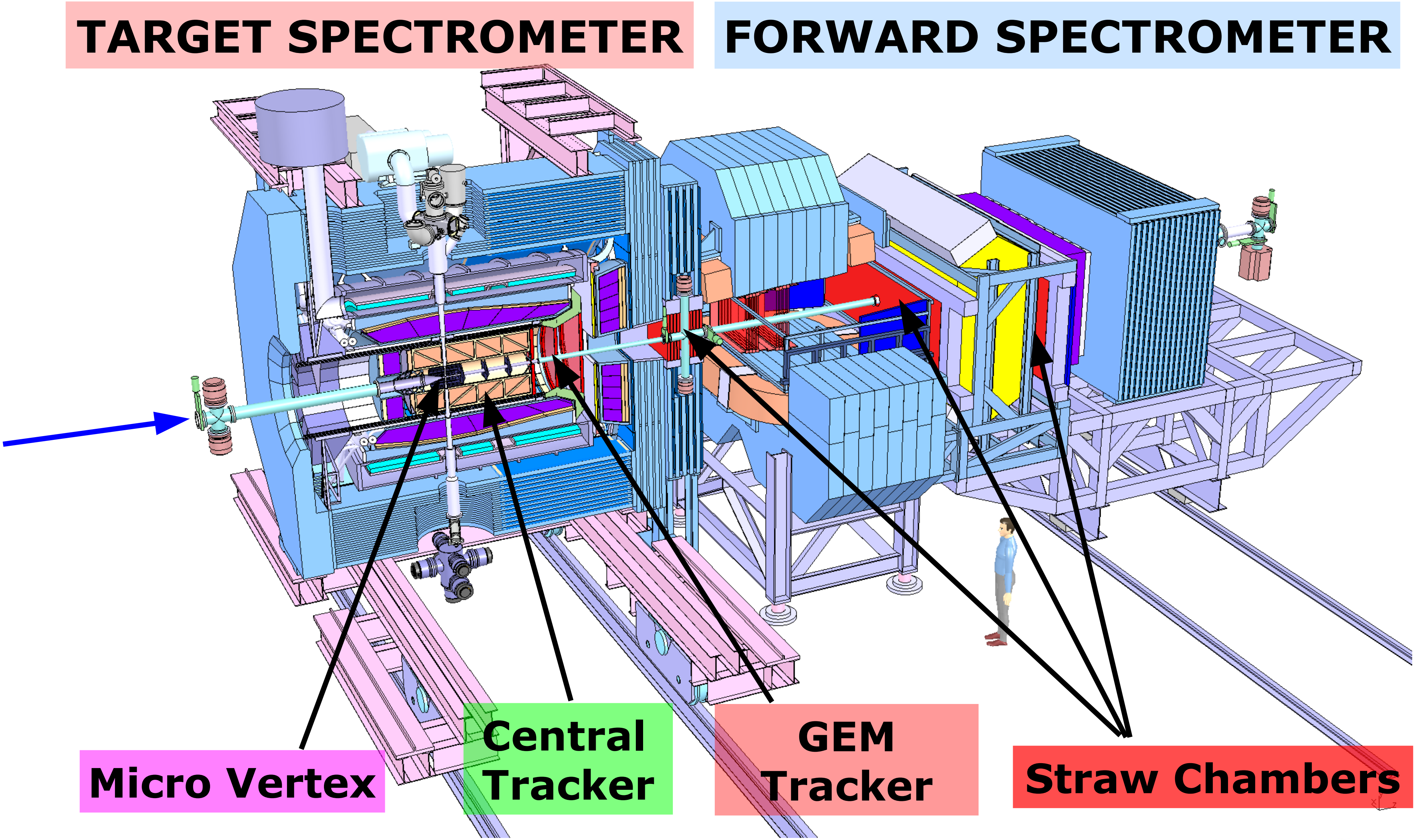

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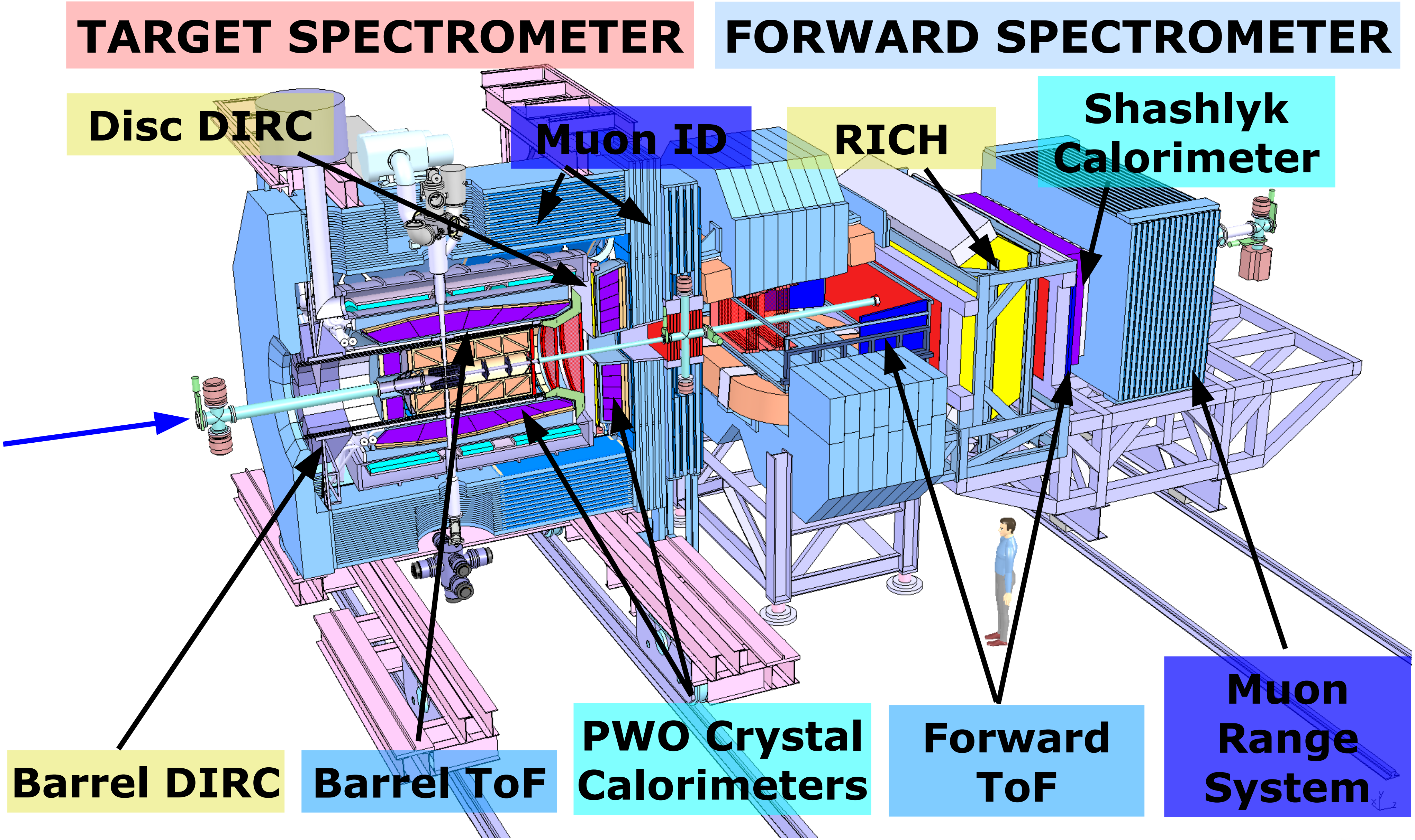


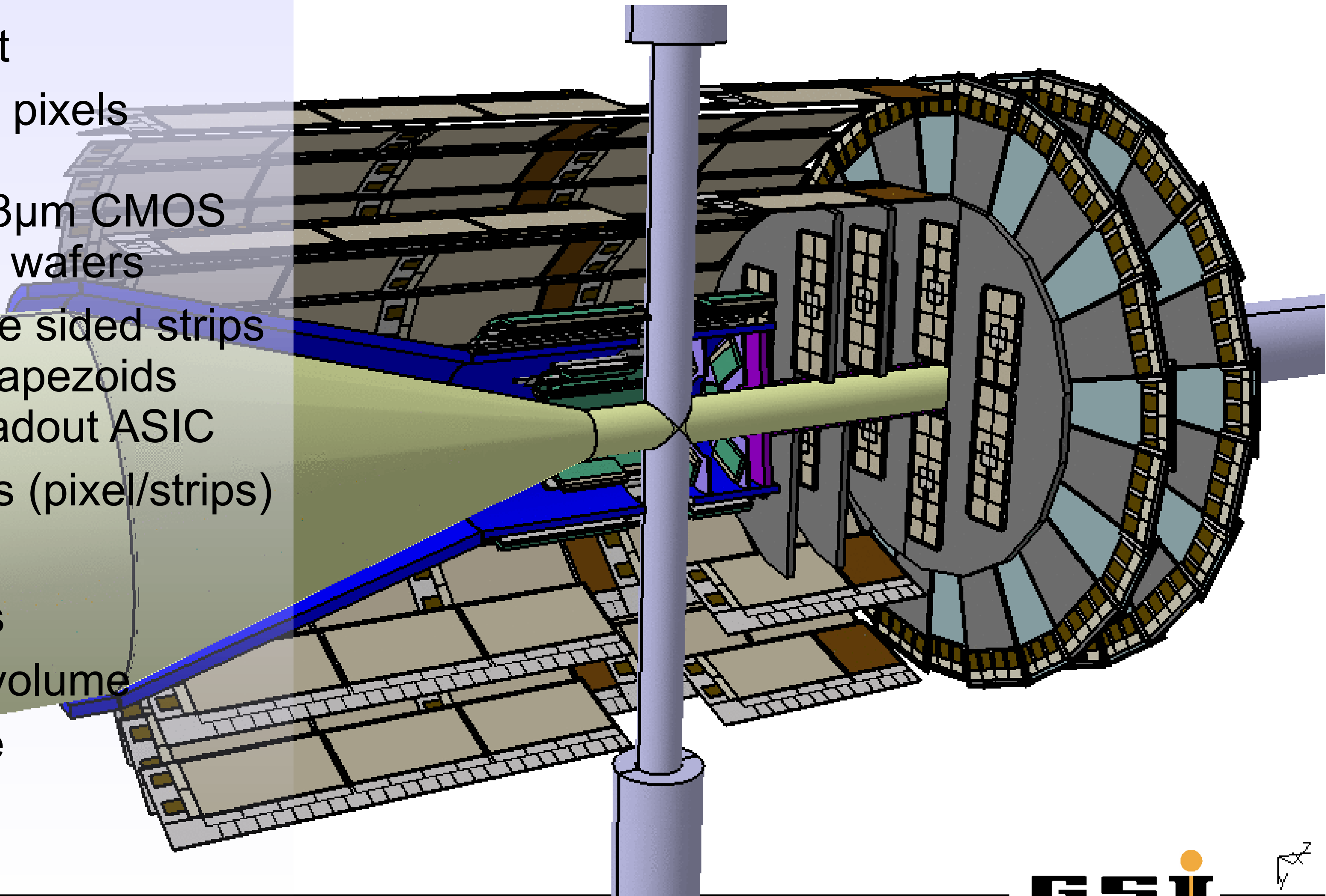
Micro Vertex Detector

Design of the MVD

- 4 barrels and 6 disks
- Continuous readout
- *Inner layers*: hybrid pixels (100x100 μm^2)
  - ToPiX chip, 0.13μm CMOS
  - Thinned sensor wafers
- *Outer layers*: double sided strips
  - Rectangles & trapezoids
  - 128 channel readout ASIC
- Mixed forward disks (pixel/strips)

Challenges

- Low mass supports
- Cooling in a small volume
- Radiation tolerance



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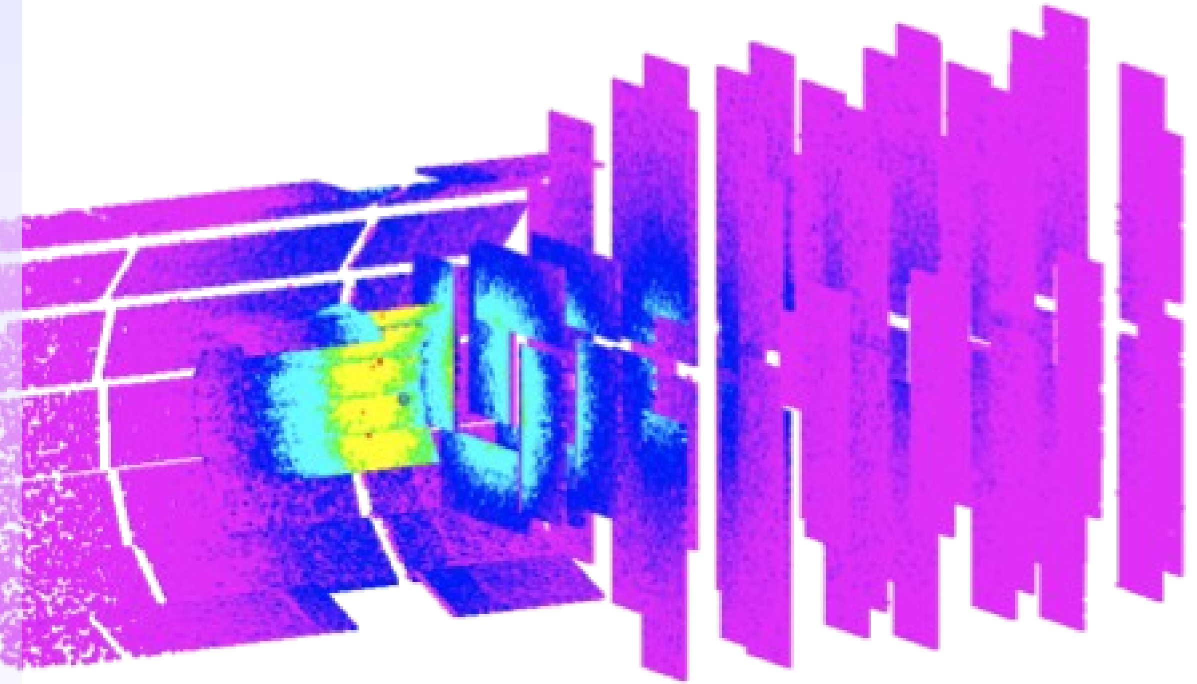


Radiation map of $\overline{\mathrm{P}}$ANDA MVD

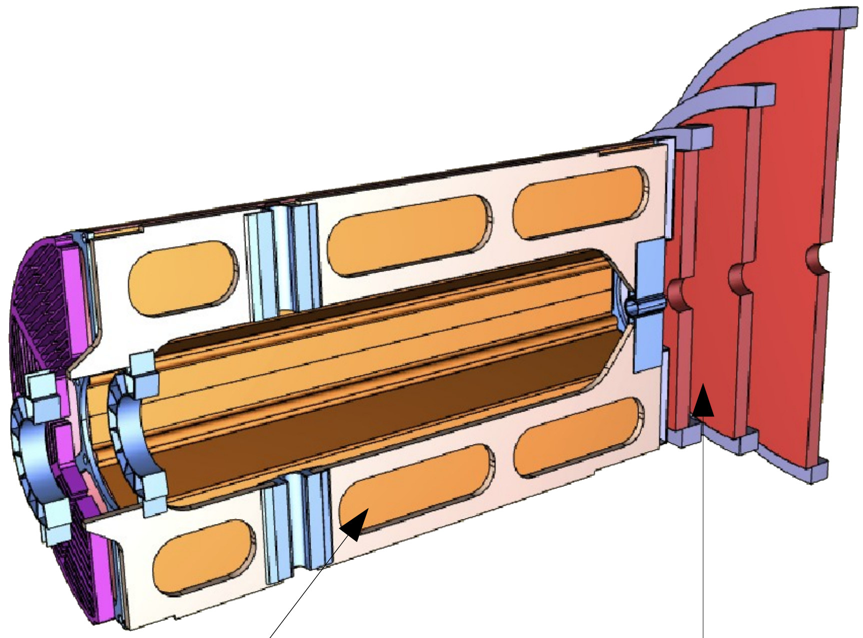
Central Tracking Detectors

Central Tracker:

- Design figures:
  - $\sigma_{r\varphi}$~150µm , σ_z~1mm
  - δp/p~1% (with MVD)
  - Material budget ~1% X_0
- Straw Tube Tracker Design:
  - 27 µm thin mylar tubes, 1 cm Ø
  - Stability by 1 bar overpressure
  - Planar layers for compactness
  - Skewed layers for z-coordinate

Forward GEM Tracker:

- Large area GEM foils
- Ultra thin coating
- 3 Stations



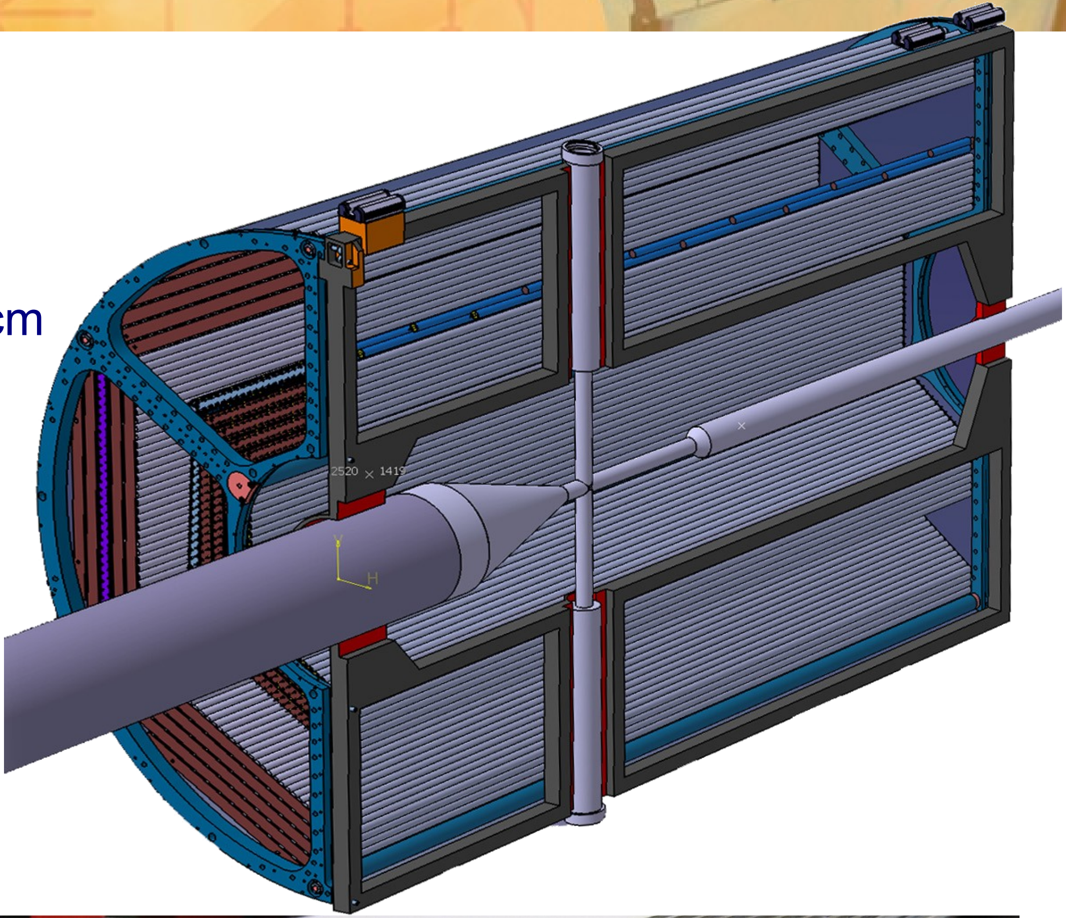
Central Tracker:
L = 150 cm
R_{in} = 15 cm
R_{out}= 42 cm
Readout 15 cm in z

GEM Tracker:
z = 120-180 cm
R_{in} = 5 cm
R_{out}= 42-88 cm
Readout at periphery

The Straw Tube Tracker

Detector Layout

- 4204 straws in 20-26 layers,
  of which 8 layers skewed at ~3°
- Tube made of 27 μm thin Al-mylar, Ø=1cm
- R_{in}= 150 mm, R_{out}= 420 mm, l=1500 mm
- Self-supporting straw double layers
  at ~ 1 bar overpressure (Ar/CO_2)

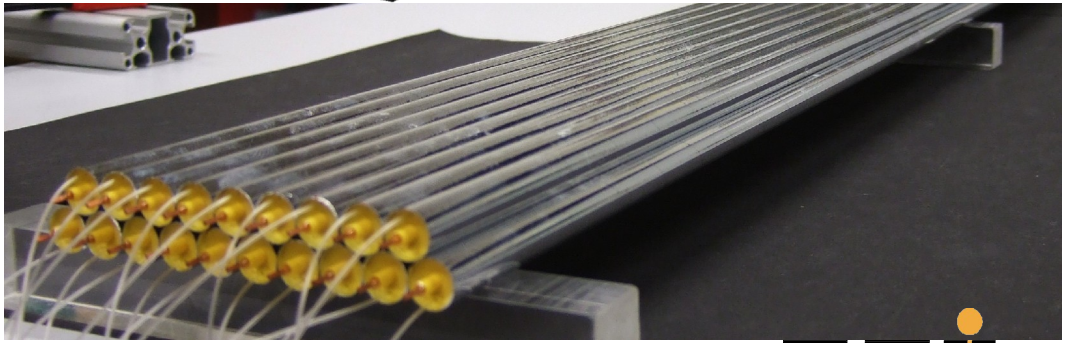


Material Budget

- Max. 26 layers,
- 0.05 % X/X_0 per layer
- Total 1.3% X/X_0

Detector Studies

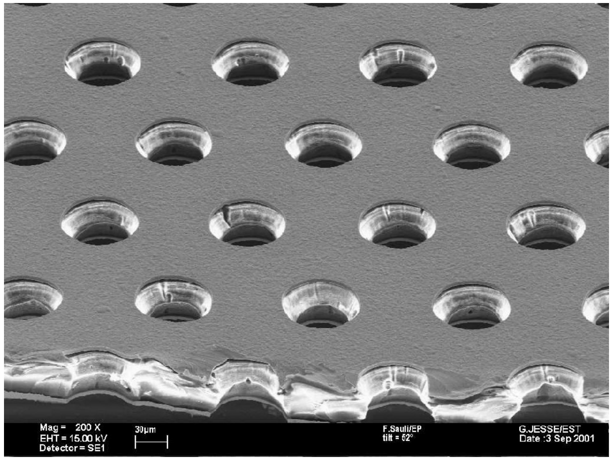
- Prototype construction & tests
- Aging tests: up to 1.2 C/cm^2
- Cosmic tests for dE/dx
- Simulations of field and detector

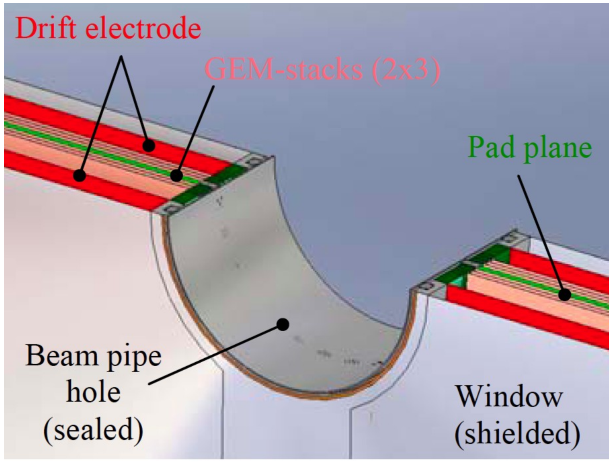


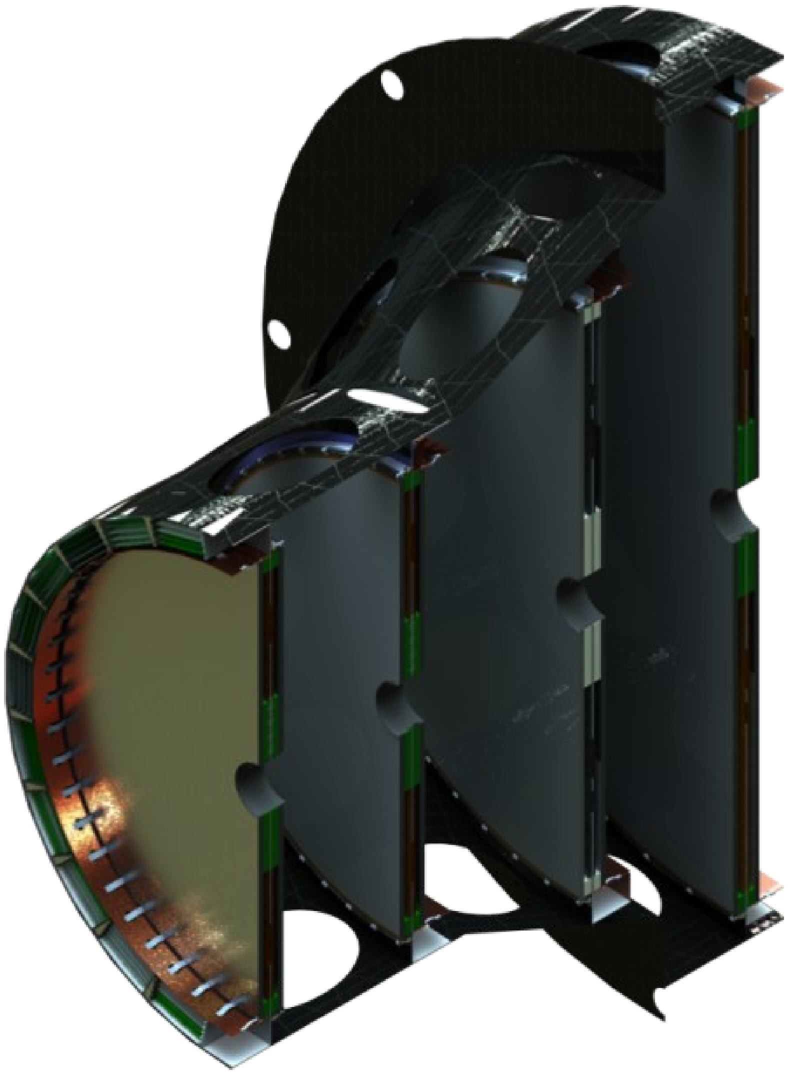
Forward GEM Tracker

Forward Tracking inside Solenoid

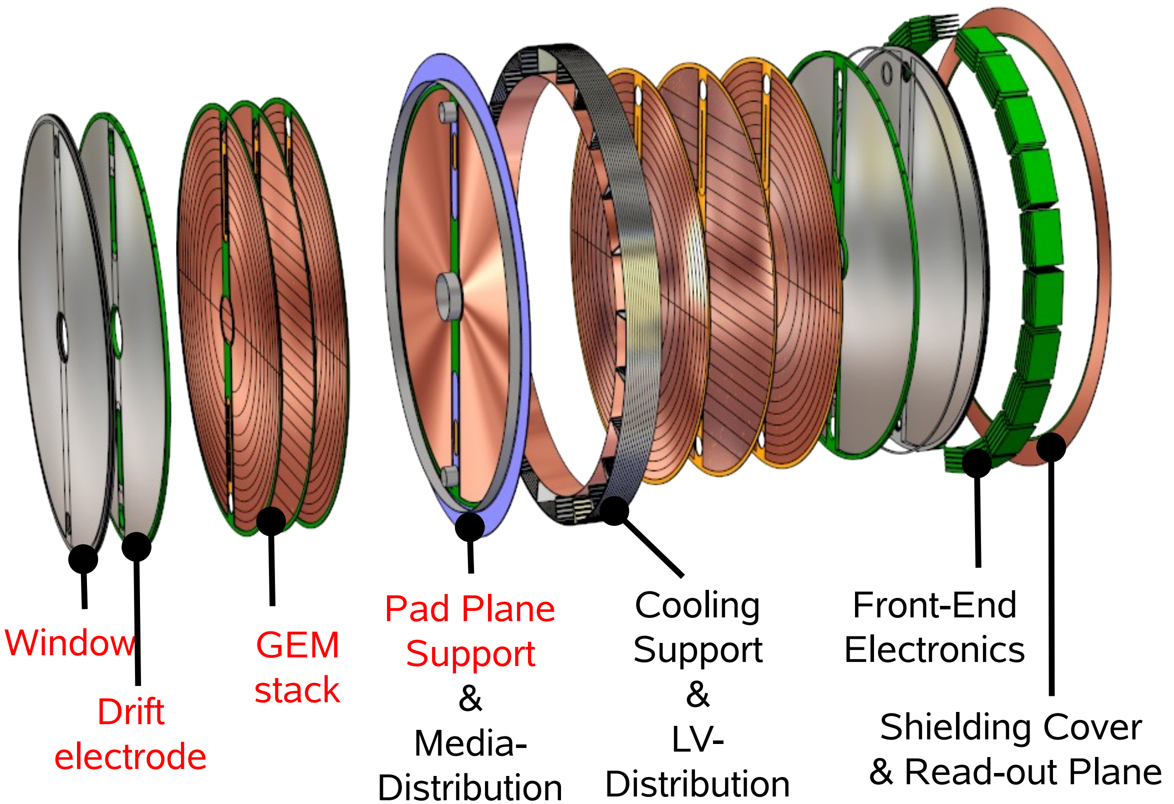
- 3-4 stations with 4 projections each
  - ➔ Radial, concentric, x, y
- Central readout plane for 2 GEM stacks
- Large area GEM foils from CERN (50μm Kapton, 2-5μm copper coating)
- ADC readout for cluster centroids
  - ➔ Approx. 35000 channels total
- Challenge to minimize material







GEM Tracker Design



Light-weight support riddle

- Modular design, stable circular arrangement
- Large GEM foils glued in the middle
- Carbon fibre reinforced support riddle
- Cable ducts with integrated power and cooling

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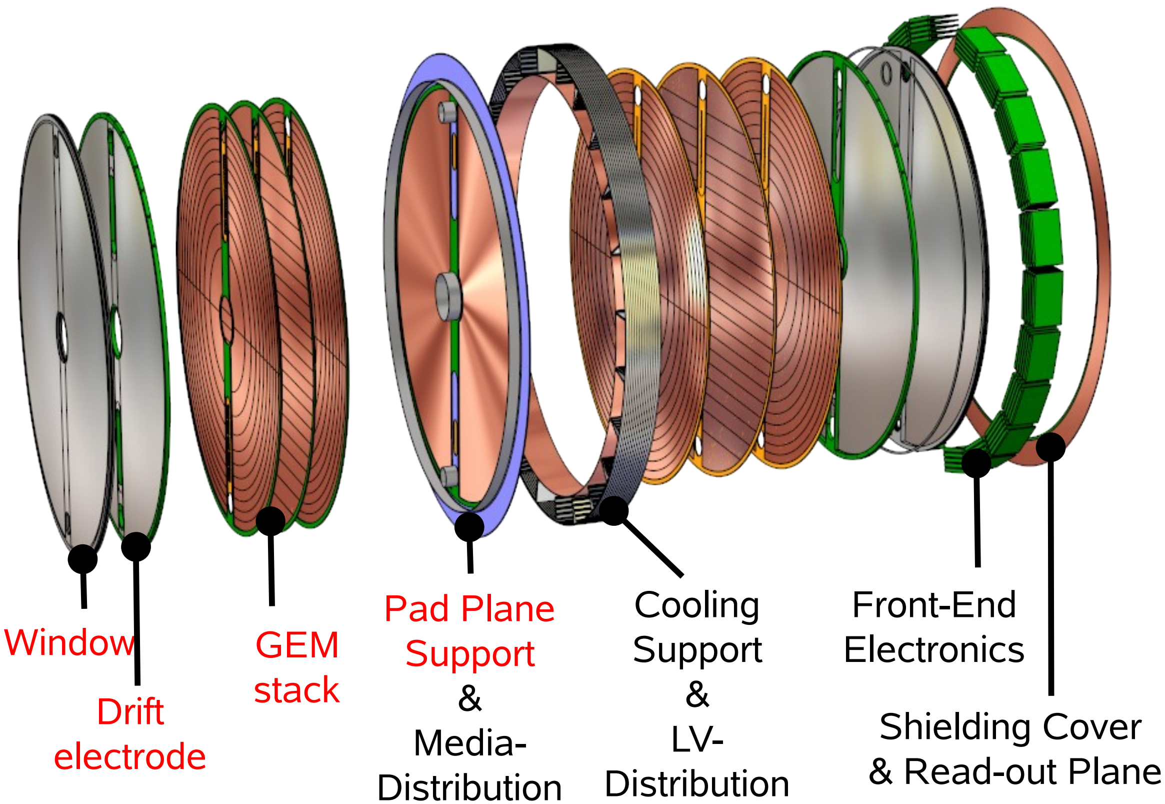

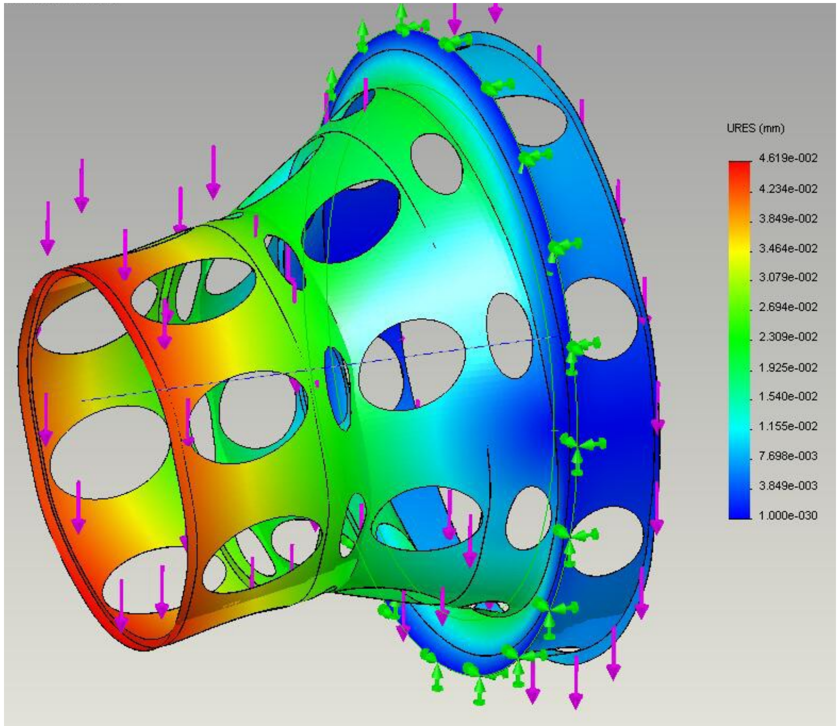

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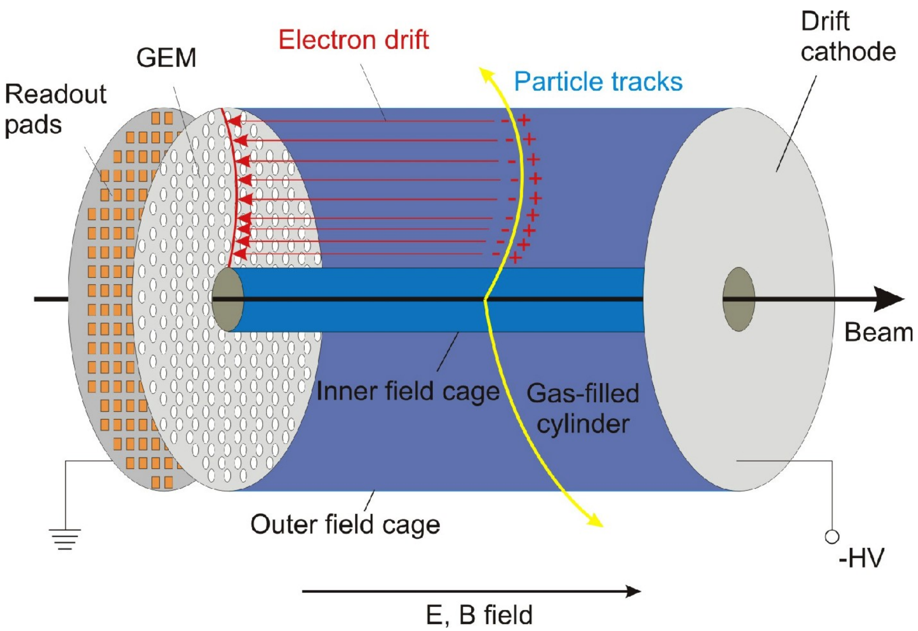
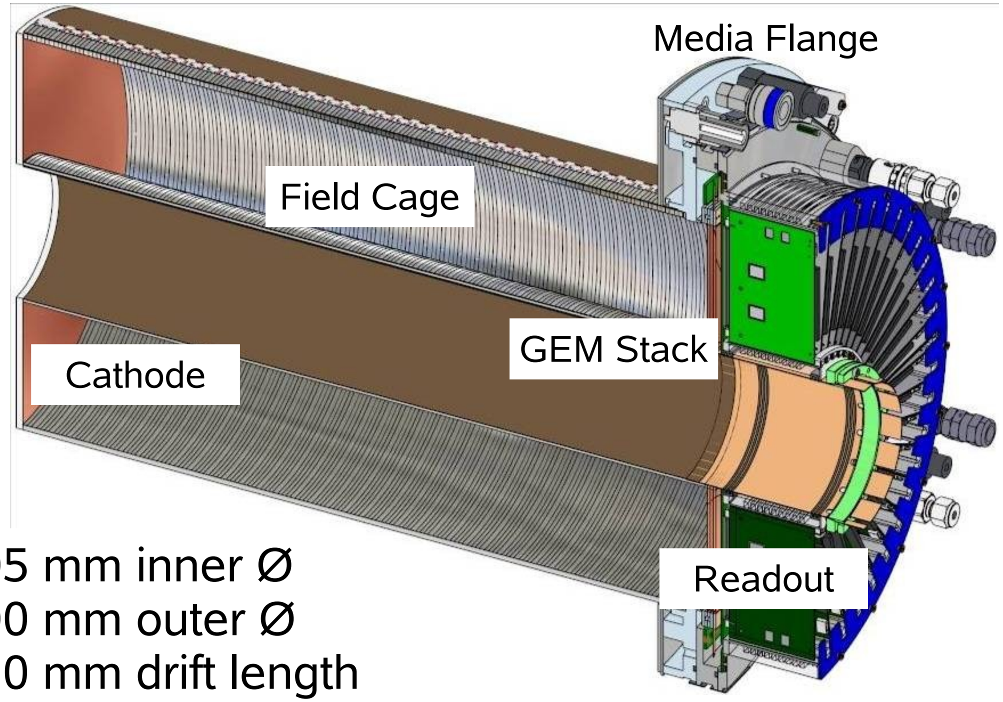
Prototype GEM TPC





105 mm inner Ø
300 mm outer Ø
730 mm drift length

GEM-TPC Concept

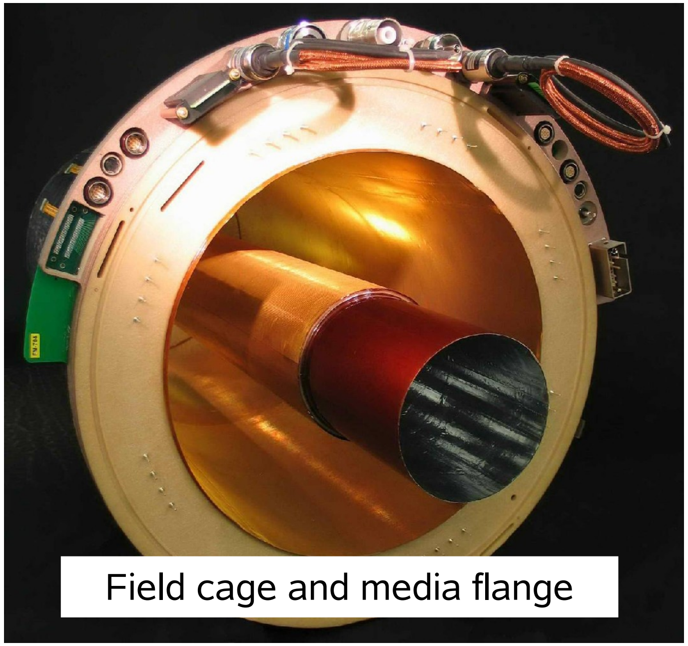
- Continuous sampling
- GEMs to reduce ion feedback
- Approx. 10k pads
- Gas Ne/CO_2 , material ~ 1% X/X_0
- Challenges: space charge and high data rate

GEM-TPC Collaboration

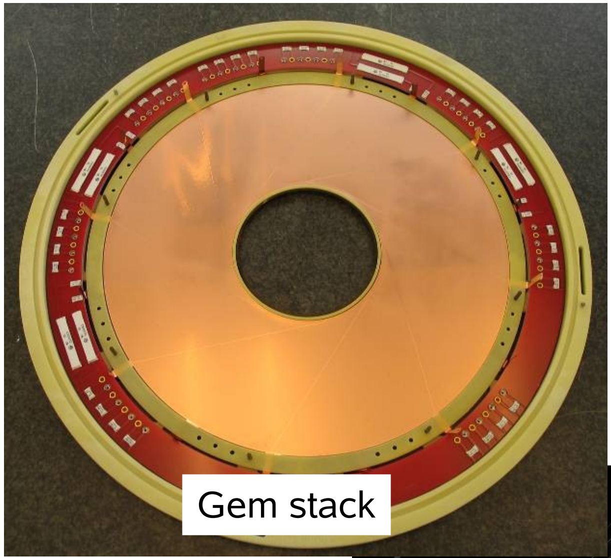
TU Munich, GSI Darmstadt, HISKP Bonn, SMI Vienna, Heidelberg University

Project started as development for PANDA, but is now continued as independent technology development

Assembly of GEM-TPC

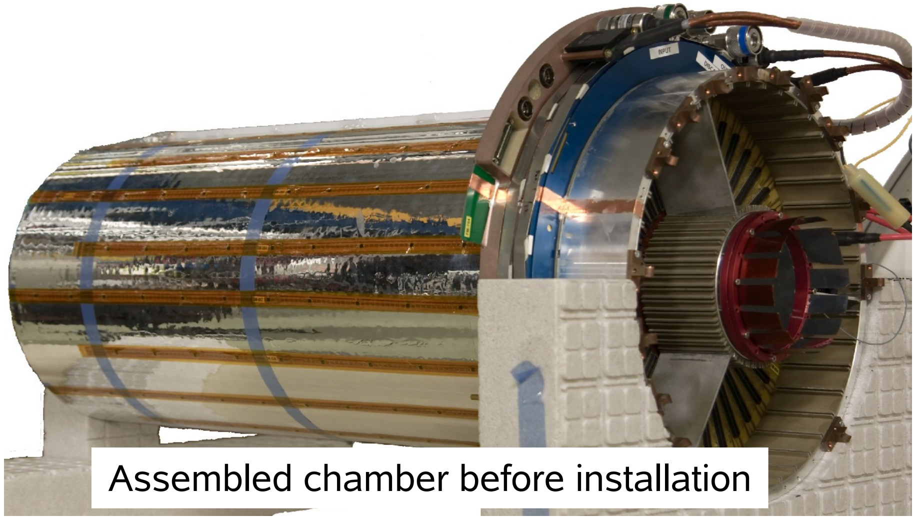


Field cage and media flange

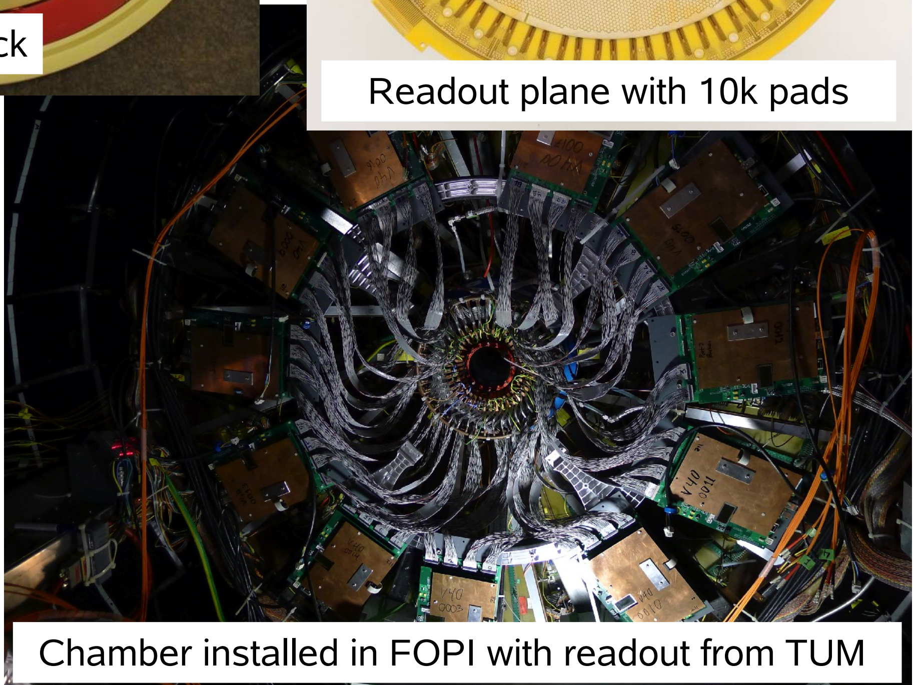


Gem stack

Readout plane with 10k pads

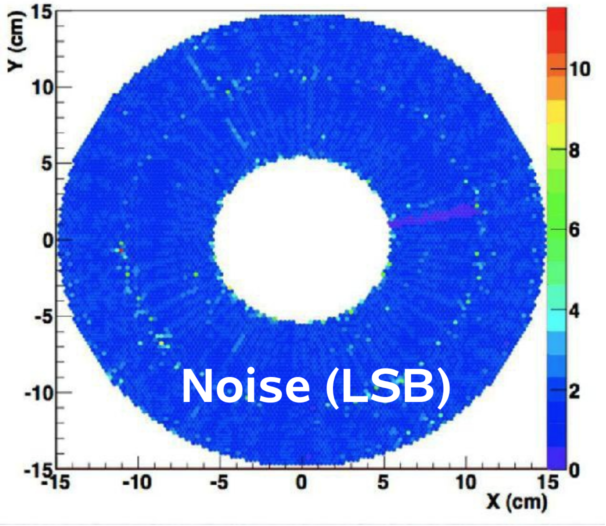


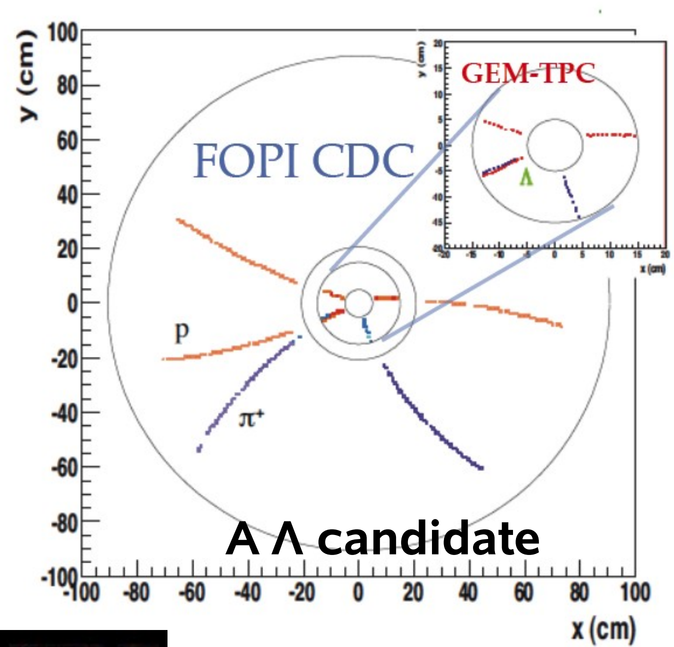
Assembled chamber before installation



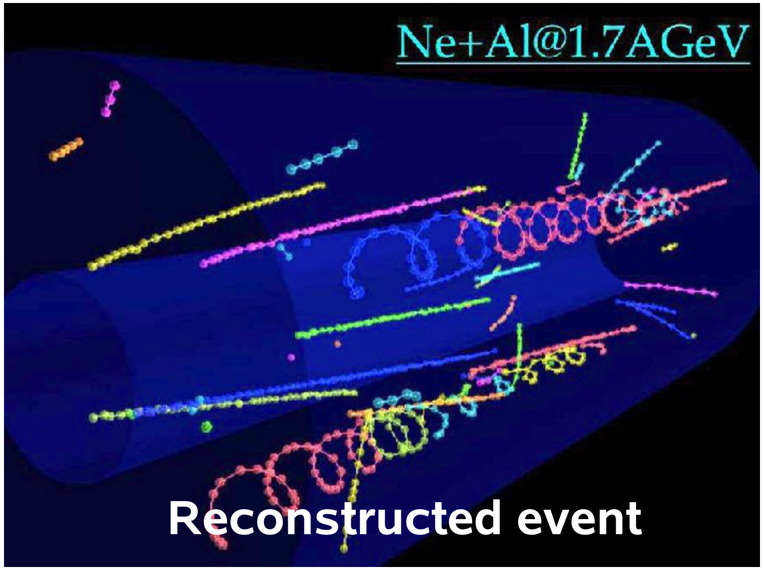
Chamber installed in FOPI with readout from TUM

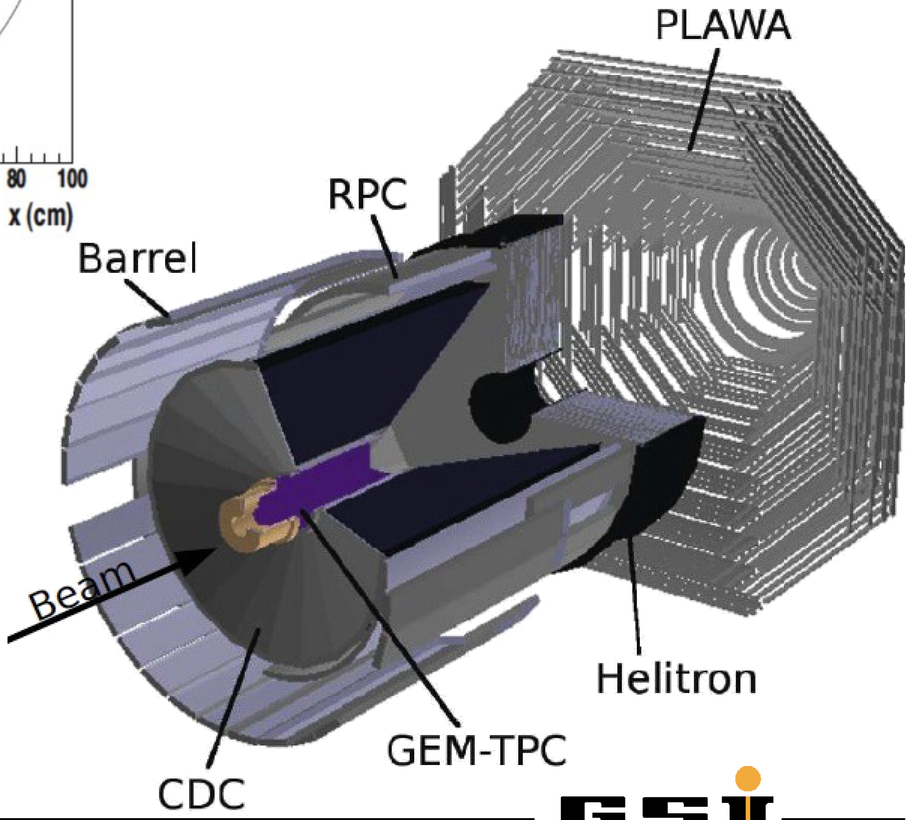
Results of GEM TPC in FOPI





GEM-TPC beam campaigns in Nov. 2010, April/May 2011 and for physics with FOPI in June 2011



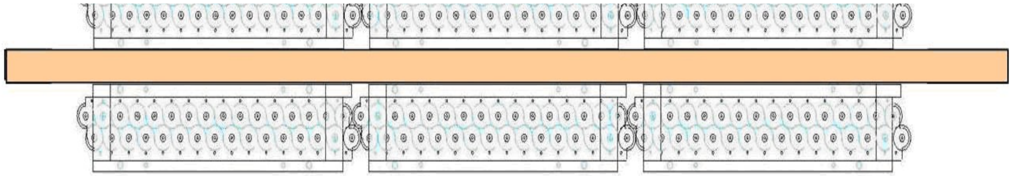


Forward Tracking

Tracking in Forward Spectrometer

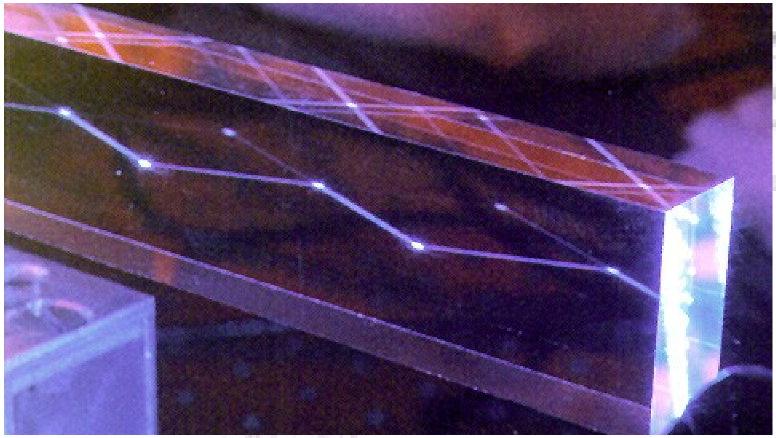
- 3 stations with 2 chambers each
  - FT1&2 : between solenoid and dipole
  - FT3&4 : in the dipole gap
  - FT5&6 : largest chambers behind dipole
- Straw tubes arranged in double layers
  - 27 μm thin mylar tubes, 1 cm Ø
  - Stability by 1 bar overpressure
- 3 projections per chamber (0°, ±5°)

Modular layout of straws

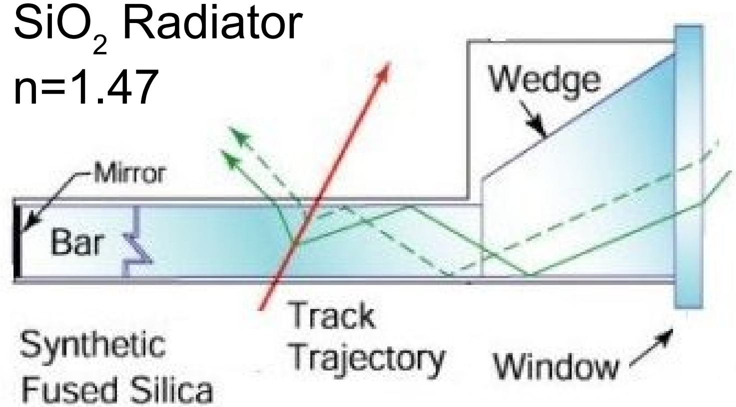


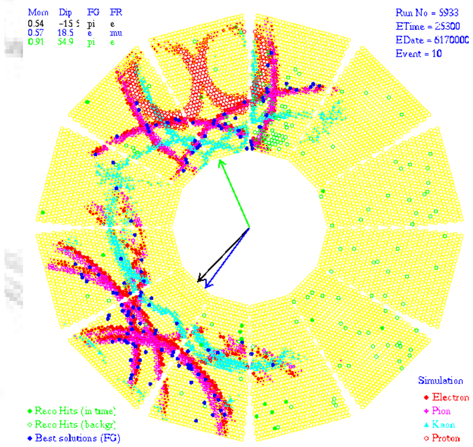
$\overline{\text{P}}$ANDA DIRC Detectors

Detection of Internally Reflected Cherenkov light

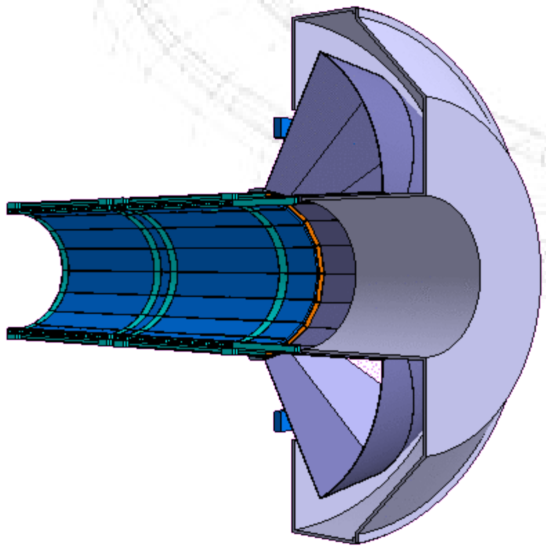


SiO_2 Radiator
n=1.47





BaBar type Barrel DIRC



- Pin hole focusing
- Large water tank
- Readout with PMTs
  (BaBar 11000,
  $\overline{\text{P}}$ANDA 7000)

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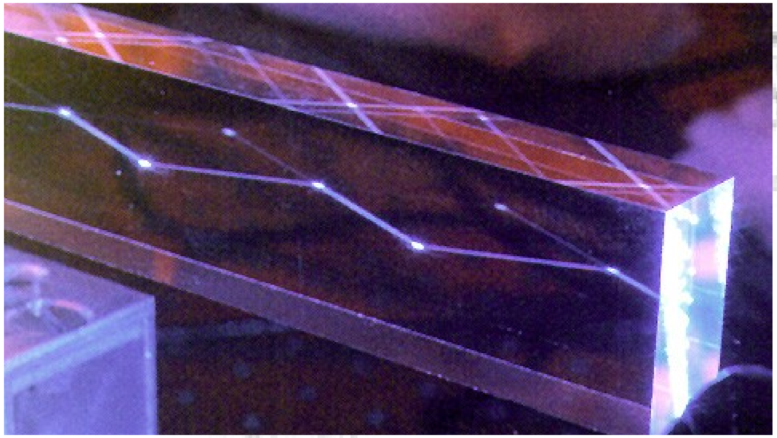
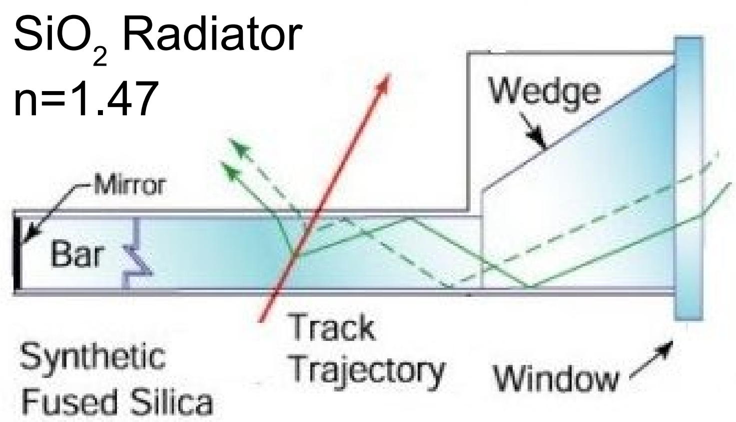
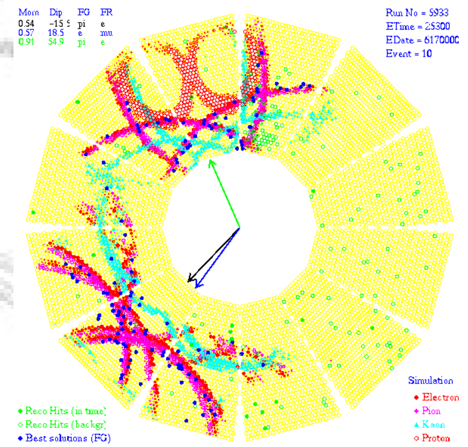
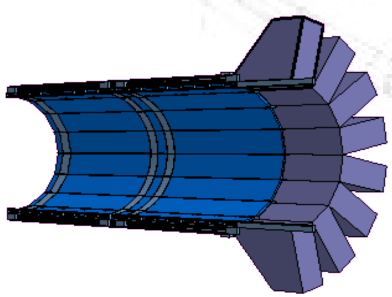


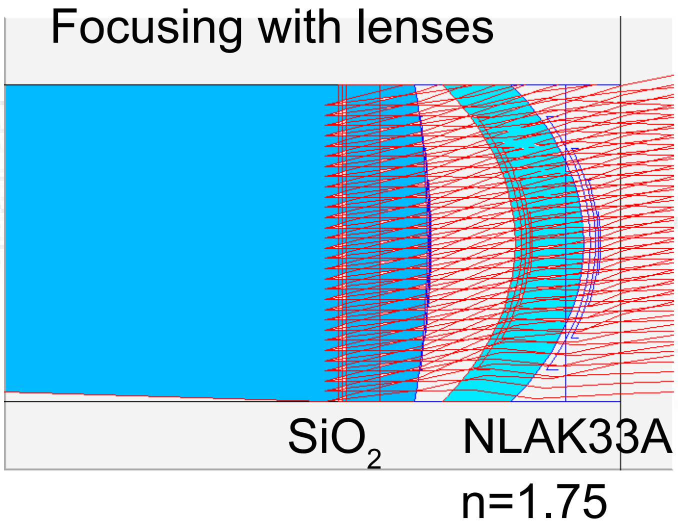




$\overline{\mathrm{P}}$ANDA Barrel DIRC

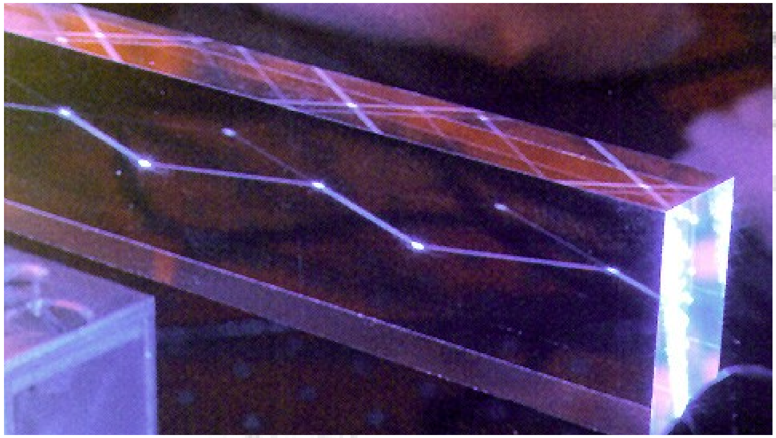


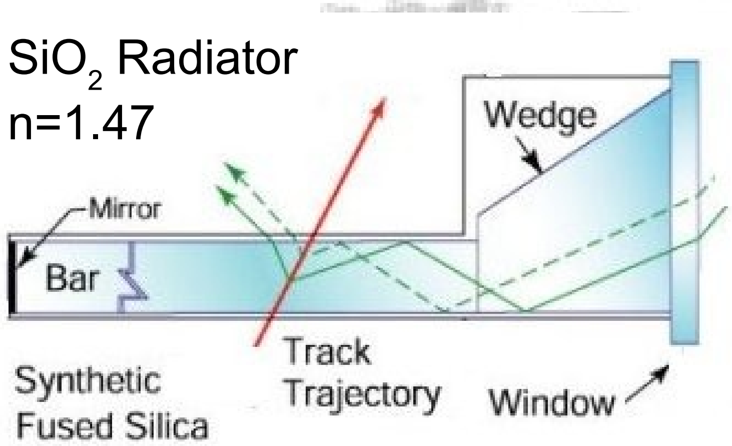
- Shorter radiator
- No large tank

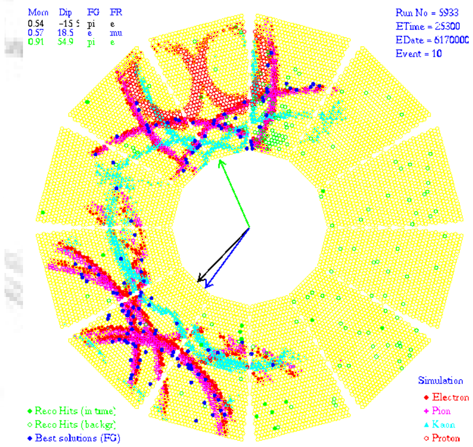


$\overline{\mathrm{P}}$ANDA DIRC Detectors

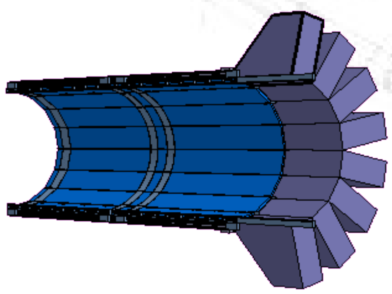
Detection of Internally Reflected Cherenkov light



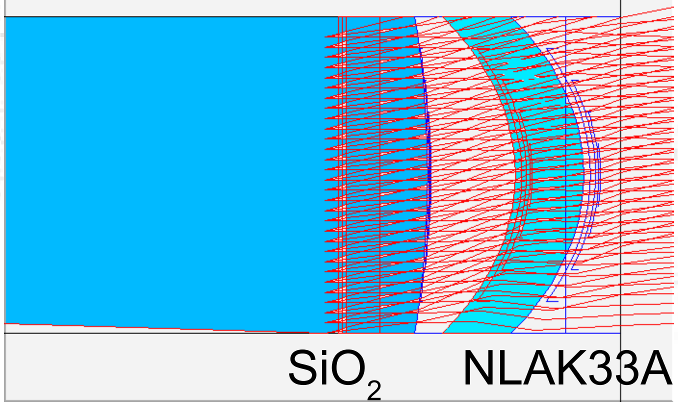




$\overline{\mathrm{P}}$ANDA Barrel DIRC

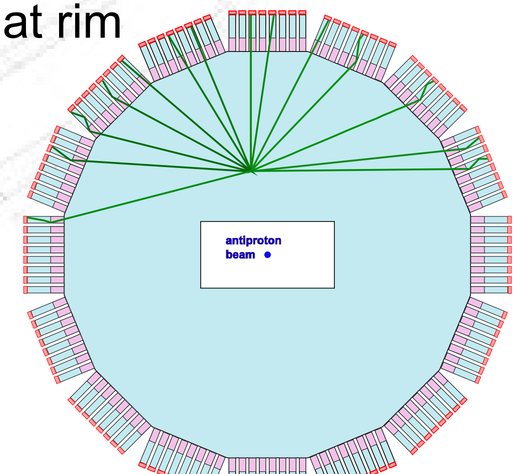


- Shorter radiator
- No large tank



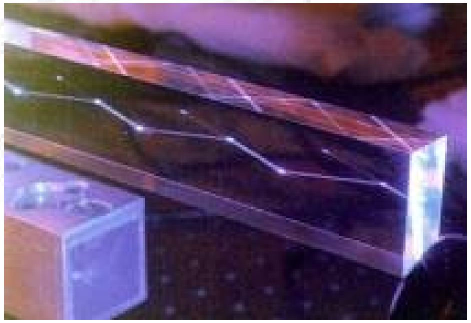
$\overline{\mathrm{P}}$ANDA Disc DIRC

- Disc shaped radiator
- Readout at rim



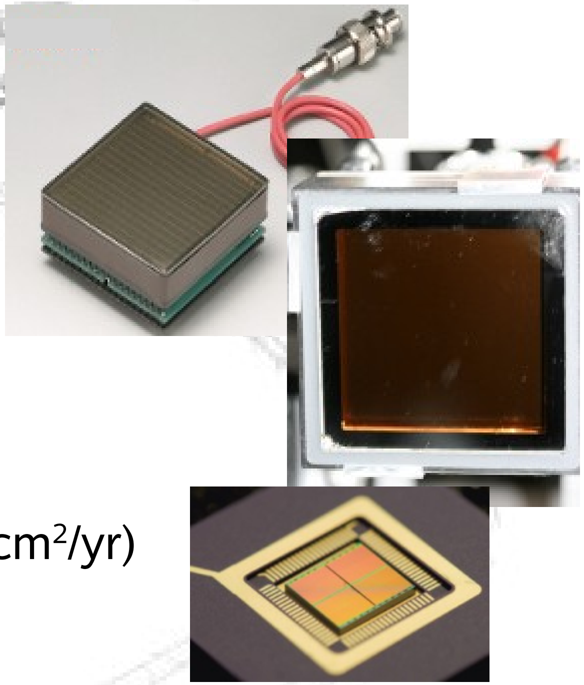
DIRC Radiator Production

- Production of large fused silica pieces (bars, plates, disk segments) is challenging
  - DIRCs require mechanical tolerances on flatness, squareness, and parallelism with optical finish and long sharp edges
    → difficult, potentially expensive, few qualified vendors worldwide
- BABAR-DIRC used bars polished to 5 Å rms, non-squareness < 0.25 mrad, successfully done for BABAR, need to qualify/retrain vendors 10+ years later
- Can afford to relax some of those specs for PANDA DIRCs due to shorter photon paths (surface roughness 10-20 Å rms, non-squareness 0.5-1 mrad, etc)
- Several good candidates for synthetic fused silica material (Heraeus, Corning)
  - Working with potential vendors in Europe and USA obtained prototype bars, plates, disk segments from several companies, verifying surfaces and angles



DIRC Photon Detection

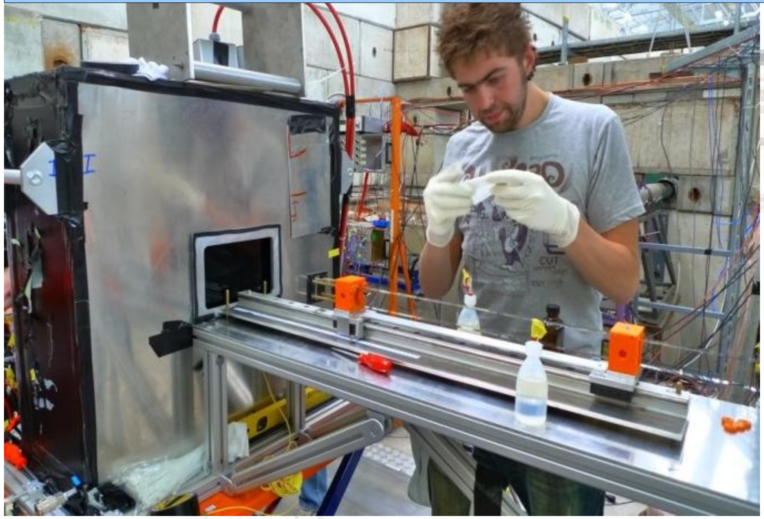
- PANDA DIRCs pose challenges to fast compact multi-pixel photon detectors
  - Single photon sensitivity, low dark count rate
  - Reasonably high photo detection efficiency
  - Fast timing: $\sigma(TTS) \approx 100$ ps
  - Few mm position resolution
  - Operation in up to 1 - 1.5 T magnetic field
  - Tolerate high rates up to 2 MHz/cm^2 (Barrel: 0.2 MHz/cm^2)
  - Long lifetime: 4-10 C/cm^2 per year at 10^6 gain (Barrel: 0.5 C/cm^2/yr)

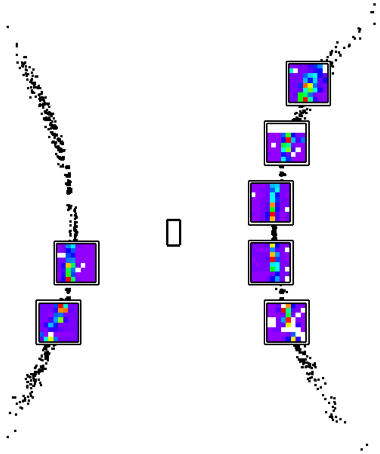


- No currently available sensor matches all criteria
  promising candidates: MCP-PMTs, MAPMTs, SiPM
- Starting aging test of two very new enhanced lifetime MCP-PMTs side-by-side:
  Hamamatsu SL-10 and Burle 85112 – both may be (almost) acceptable for barrel DIRC
- Digital SiPM (Philips) promising sensor for Disk: excellent timing and lifetime, integrated
  readout electronics, masking of hot pixels
  But: needs cooling, needs redesign for single photons, new technology, prototypes only

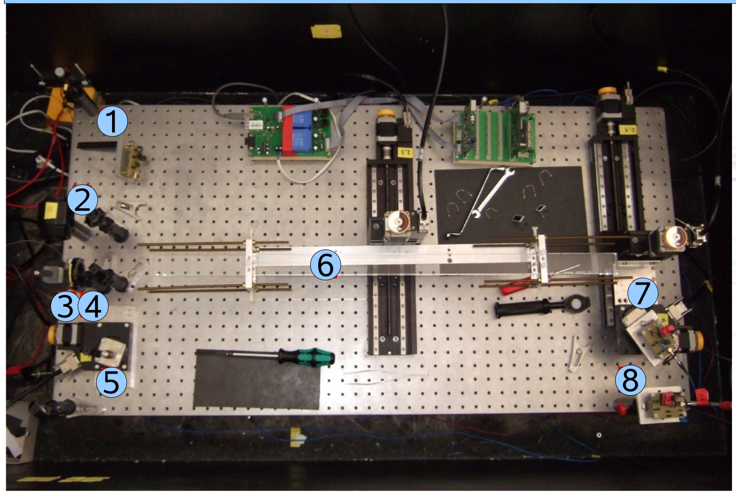
DIRC Prototype Work

DIRC Testbeam at CERN, July 2011

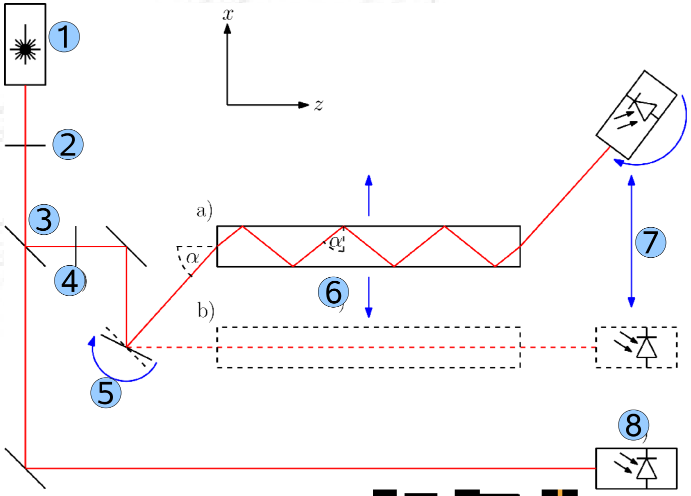




Radiator Testbench at GSI



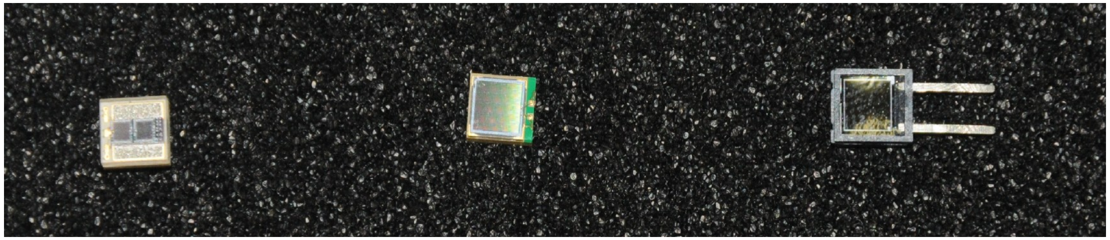
1) Laser (405, 532, 635 nm)
2) Polarizer
3) Beam splitter
4) Diaphragm
5) Brewster mirror
6) Bar on x, y stage
7) Value Diode
8) Reference Diode



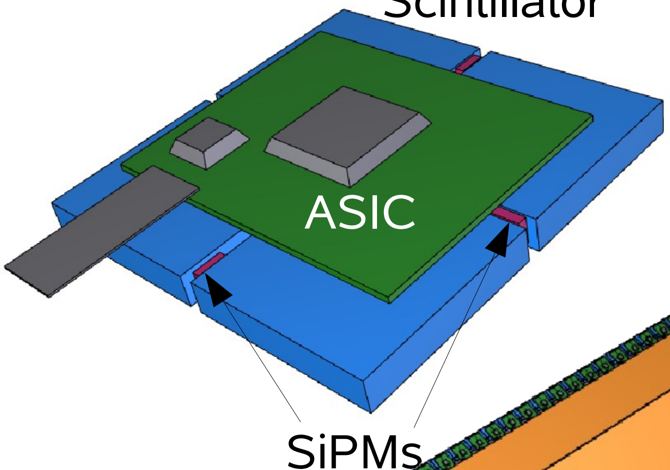
Scintillator Tile Hodoscope

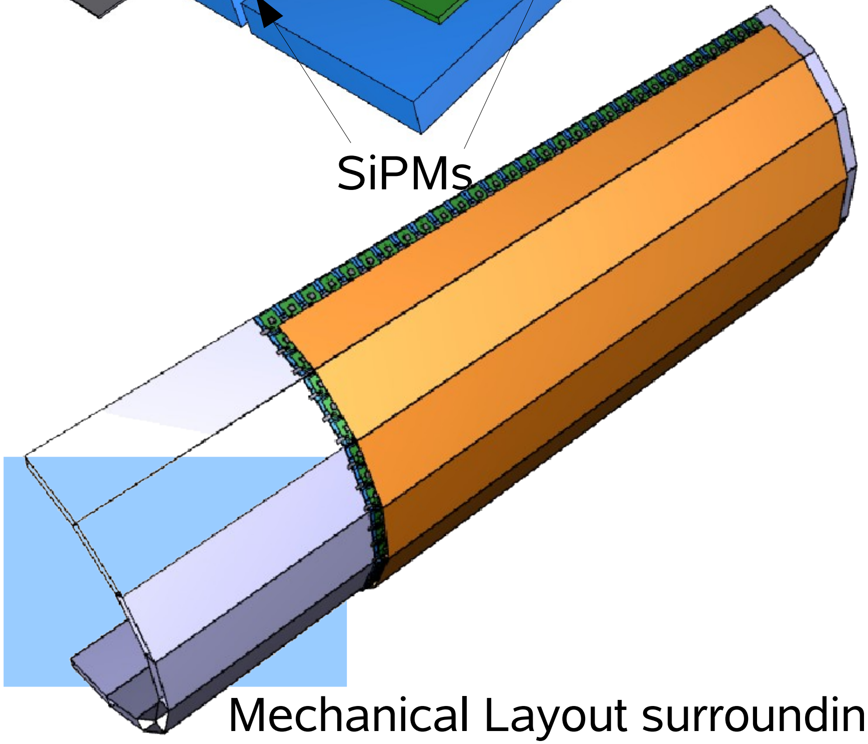
Detector for ToF and event timing

- Scintillator tiles 3x3x0.5 cm^3
  - ➔ BC404, BC408 or BC420
  - ➔ Space points with precision timing
  - ➔ Lowest possible material budget
- Photon readout with 2 SiPMs (3x3 mm^2)
  - High PDE, time resolution, rate capability
  - Work in B-fields, small, robust, low bias
  - *High intrinsic noise*
  - *Temperature dependence*
- Goal for time resolution: 100 ps
- ASIC for SiPM readout



Quad Module



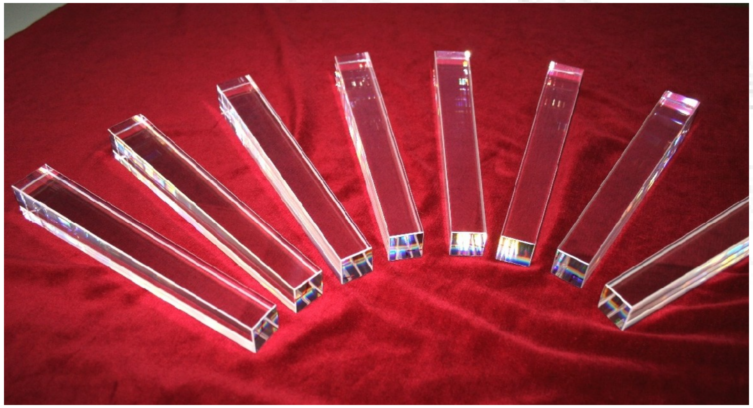


Mechanical Layout surrounding the DIRC: 5760 tiles

Electromagnetic Calorimeters

$\overline{\text{P}}$ANDA PWO Crystals

- PWO is dense and fast
- Low γ threshold is a challenge
- Increase light yield:
  - improved PWO II (2xCMS)
  - operation at -25°C (4xCMS)
- Challenges:
  - temperature stable to 0.1°C
  - control radiation damage
  - low noise electronics
- Delivery of crystals started



Electromagnetic Calorimeters

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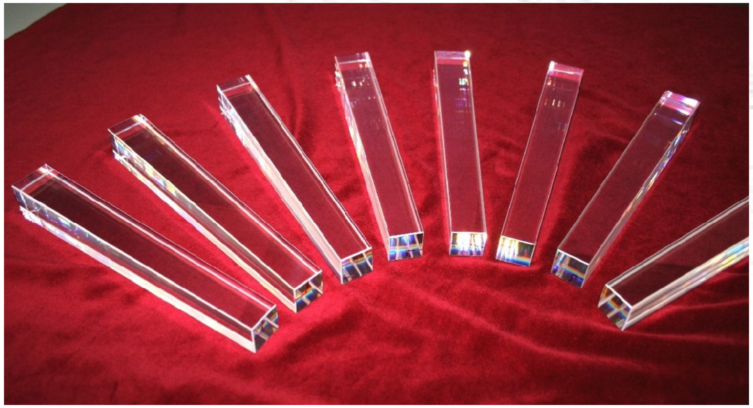
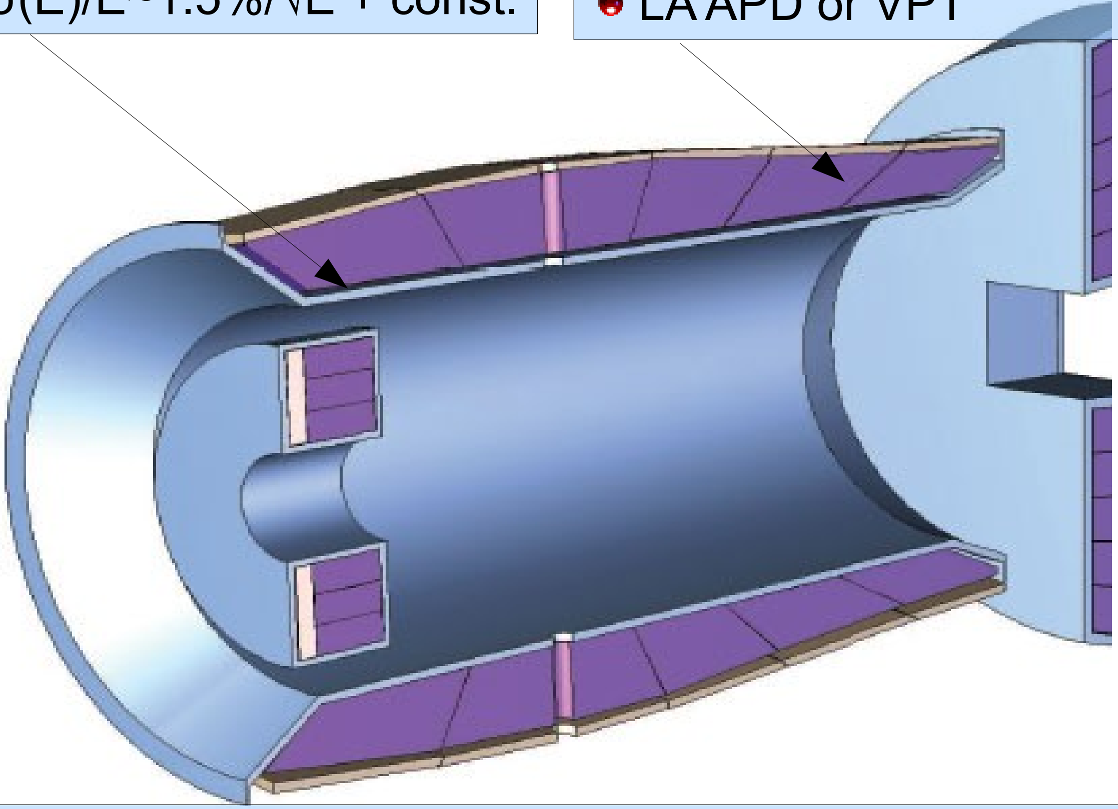


Barrel Calorimeter

- 11000 PWO Crystals
- LAAPD readout, $2x1cm^2$
- $\sigma(E)/E \sim 1.5\%/\sqrt{E}$ + const.

Forward Endcap

- 4000 PWO crystals
- High occupancy in center
- LA APD or VPT

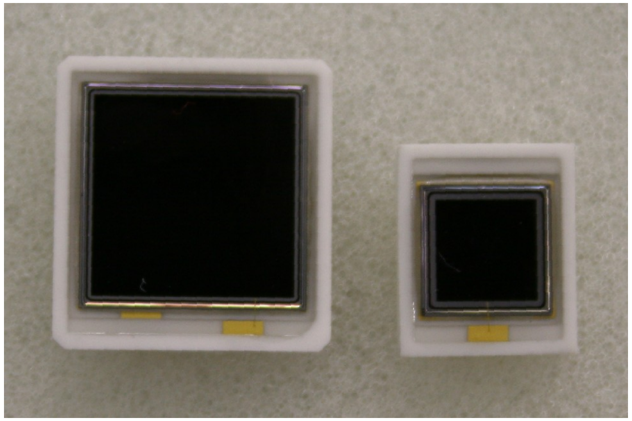


Backward Endcap for hermeticity, 560 PWO crystals
Forward EMC shashlyk behind dipole

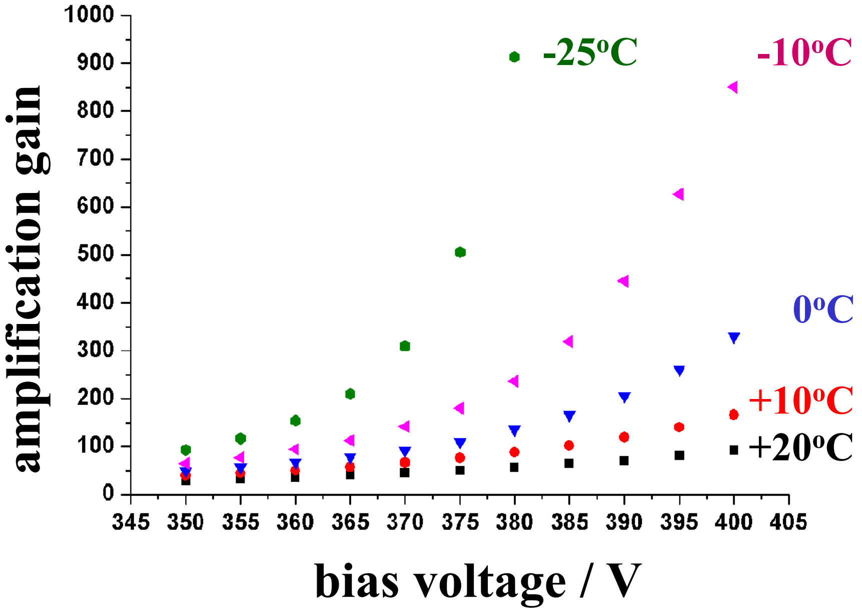
Readout with Large Area APD

- Development of LA APDs with Hamamatsu
  - Large area at acceptable capacitance: 4x area of previously available APDs
  - Excellent performance at RT and -25°C
  - Radiation tolerance up to 10^{13} protons/cm^2 in particular at -25°C

PANDA CMS



1x1 cm^2 0.5x0.5 cm^2



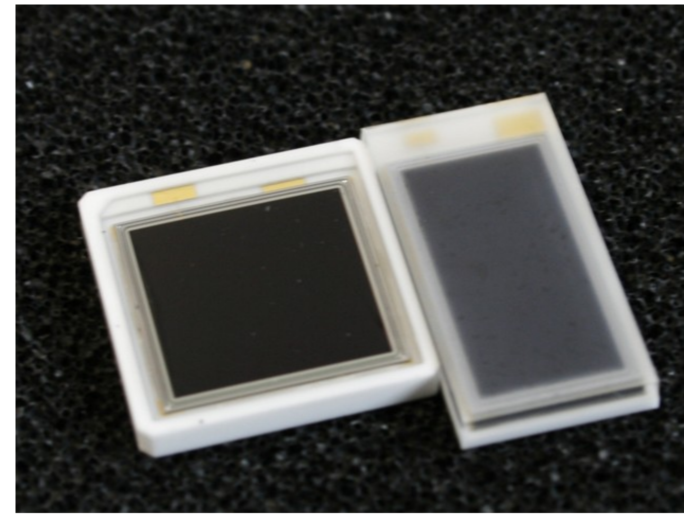
- Screening of all APDs needed to reach best resolution and stability
- A mass screening facility is under construction at GSI

Courtesy A. Wilms

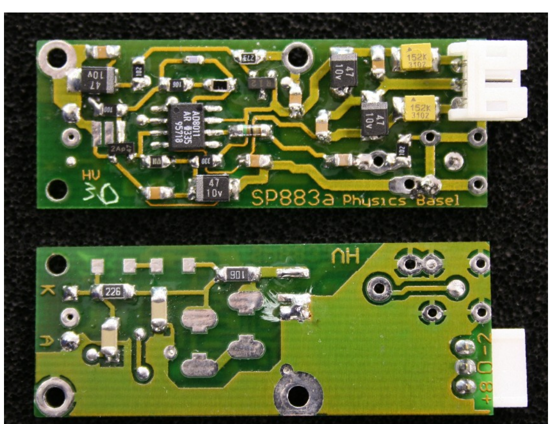
Readout with Large Area APD

- Development of LA APDs with Hamamatsu
  - Large area at acceptable capacitance: 4x area of previously available APDs
  - Excellent performance at RT and -25°C
  - Radiation tolerance up to 10^{13} protons/cm^2 in particular at -25°C
  - To accommodate 2 APDs per crystal: rectangular APD with 7x14 mm^2
- Readout via discrete amplifier or APFEL ASIC

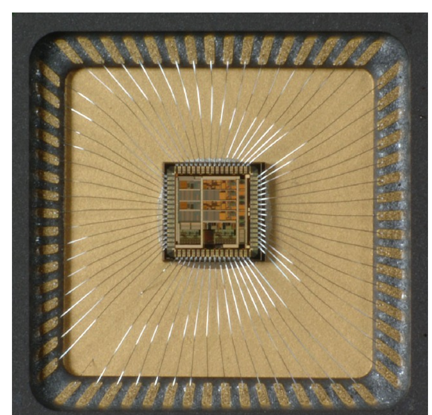
PANDA APDs



10x10 mm^2 and 7x14 mm^2



18mm

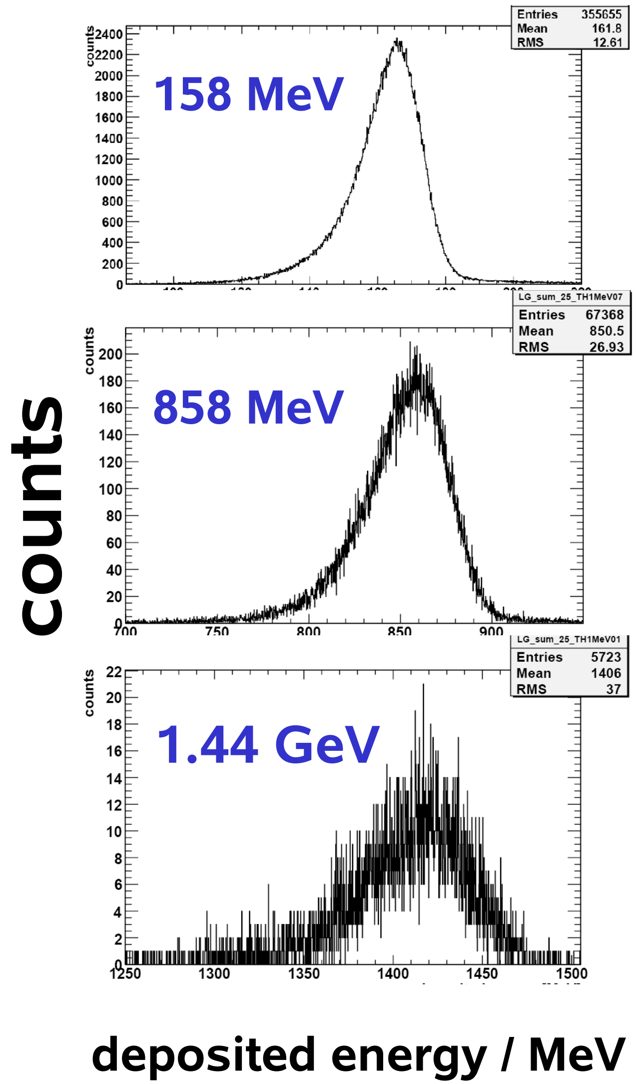


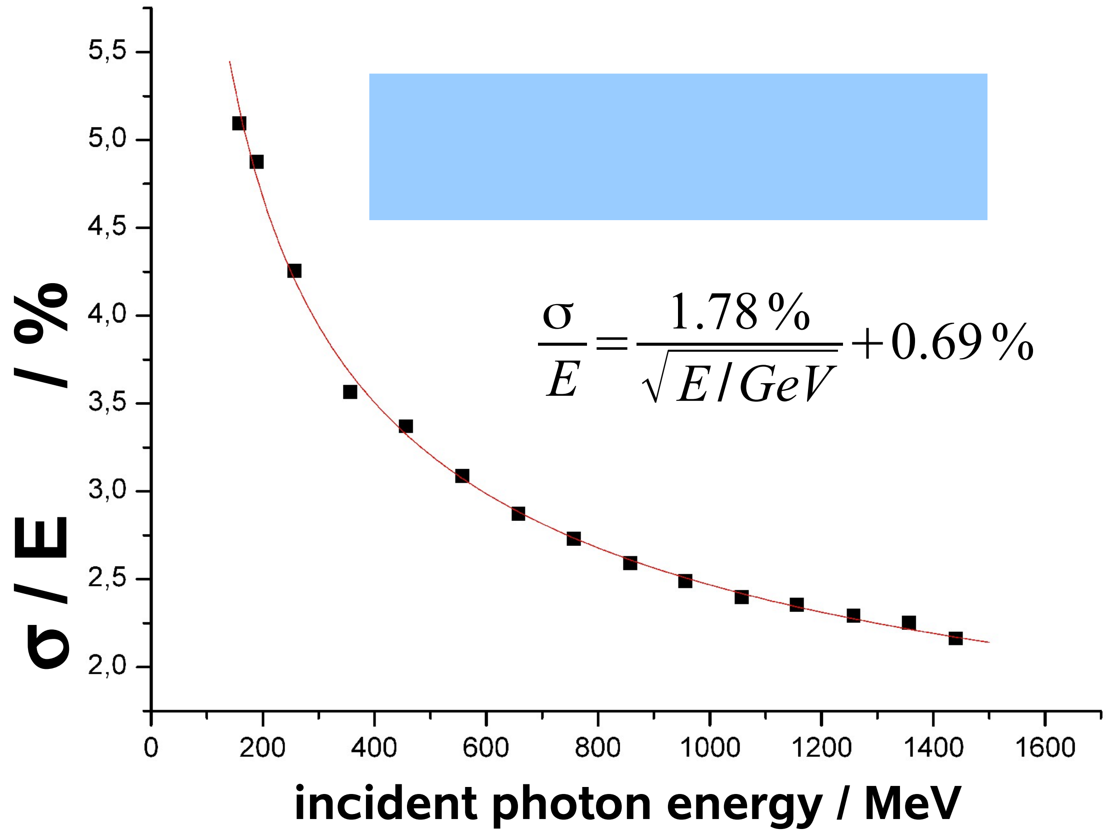
- 2 channels/ 2 ranges
- overall range 1 – 10.000
- noise level (cooled) < 2 MeV

Courtesy A. Wilms

PWO Prototype Performance

Beam Tests at MAMI



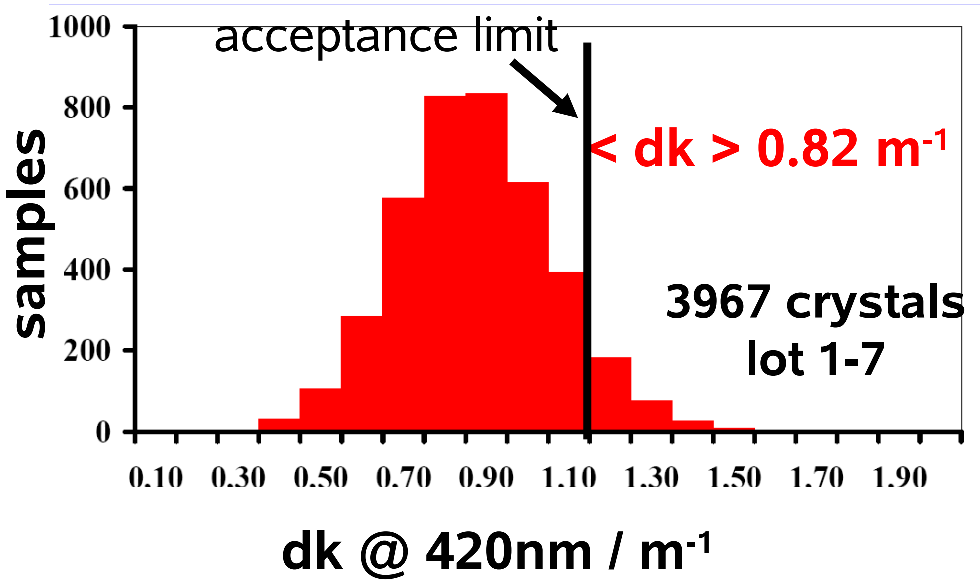


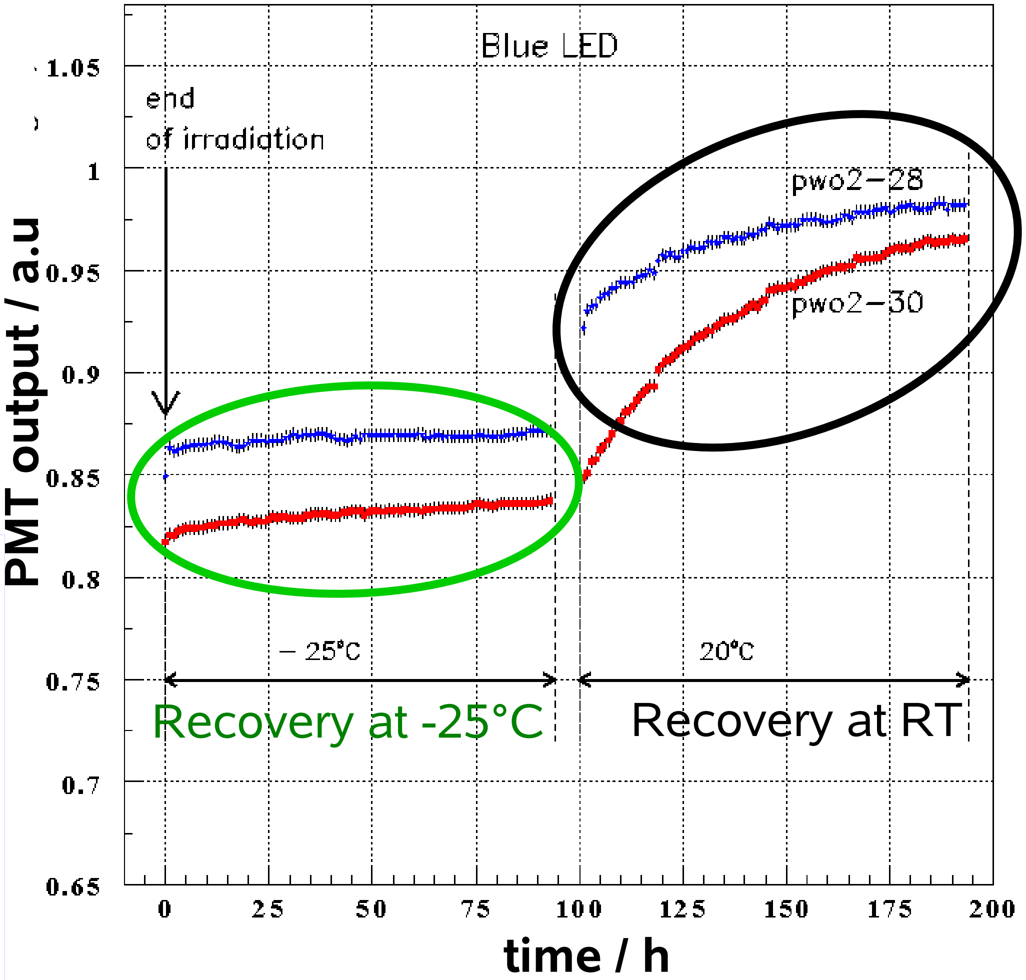
- Single 1x1 cm² APD with discrete amplifier
- Digitization: shaping /peak-sensing ADC
- Even improved with 100 MHz sampling ADC
- Ongoing tests with APFEL ASIC

Courtesy R. Novotny

Radiation Damage in PWO

- Radiation induced absorption reduces light yield
- At RT recovery by annealing
- At -25°C annealing is slower
- PANDA crystals: control radiation induced absorption loss dk



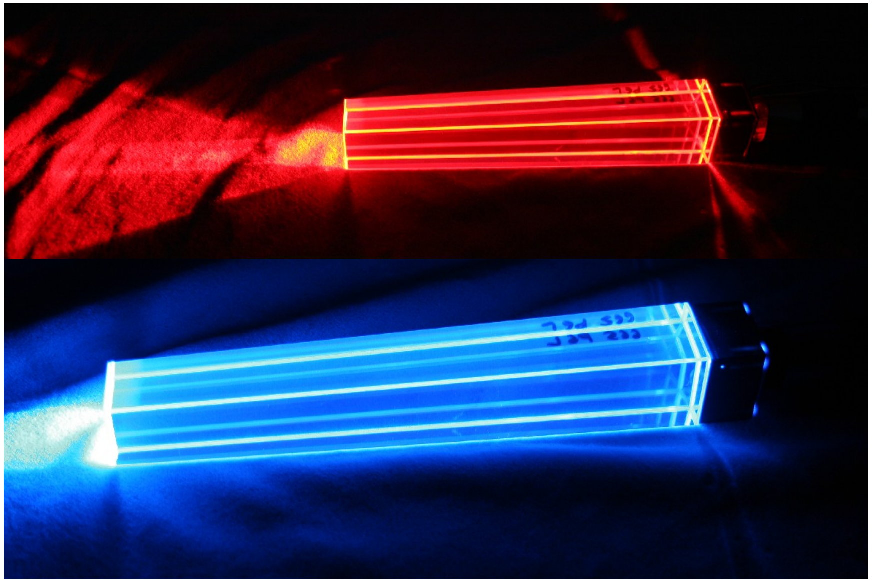


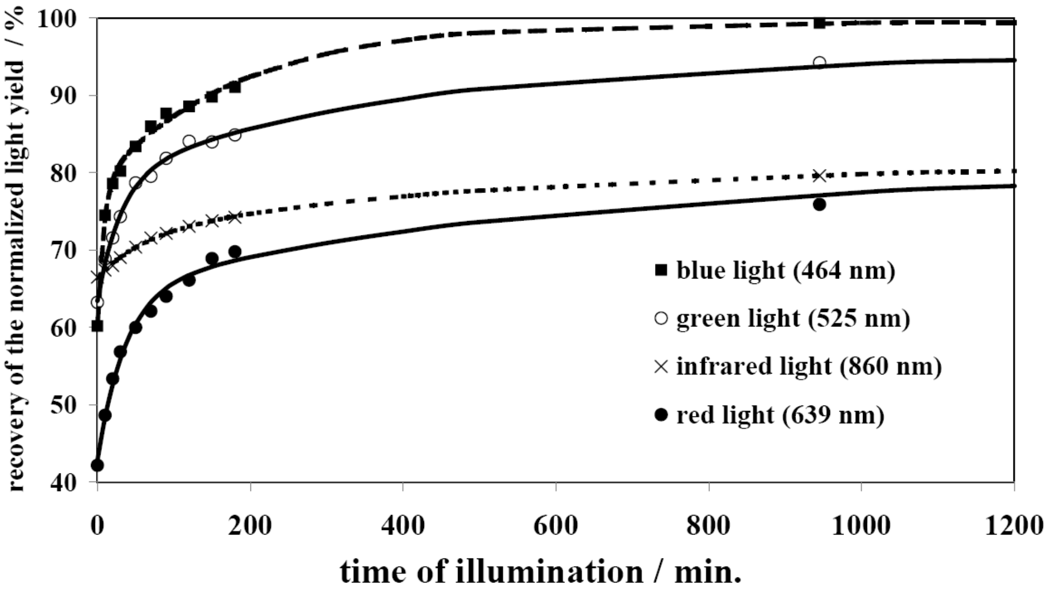
Courtesy R. Novotny

Stimulated Recovery of PWO

Discovery of stimulated recovery

- Measurement at T=-25°C
- Irradiation with 30 Gy (^{60}Co)
- Damage and recovery characterized by light yield (^{60}Co)
- Illumination with LEDs of different color
- Crystals of different rad. hardness (dk)





- Online recovery with IR light
- Fast recovery with blue light

Courtesy R. Novotny

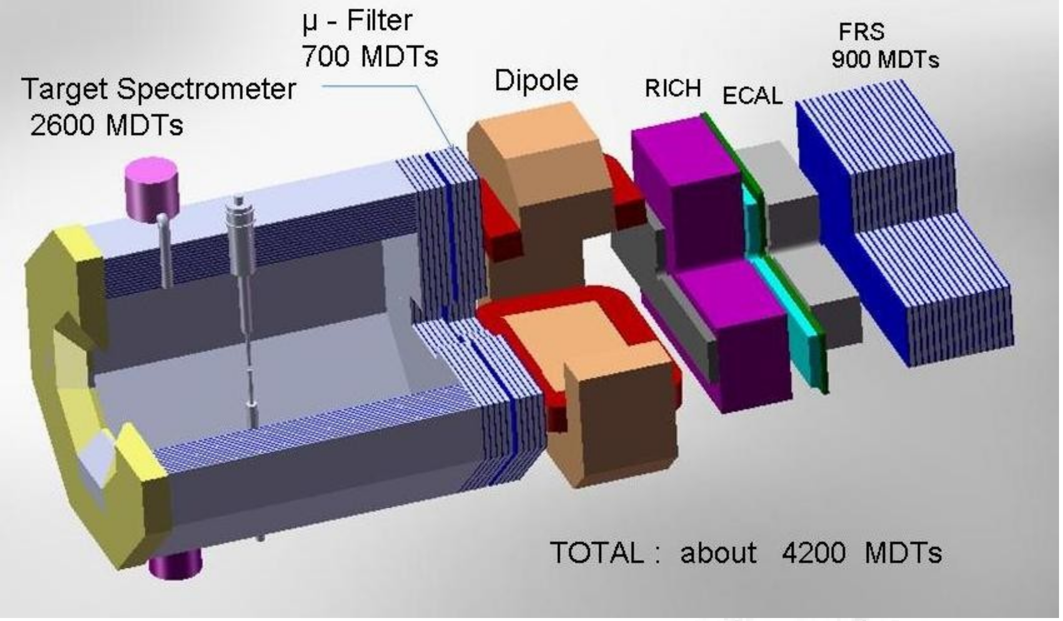
Muon Detector System

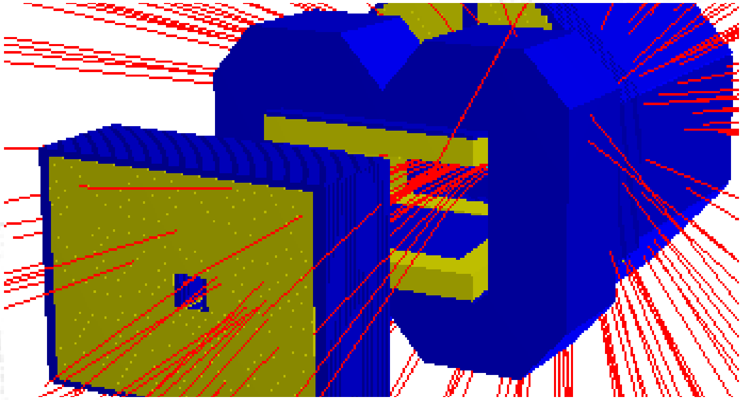
Muon system rationale:

- Low momentum particles
- High background of pions
- Multi-layer range system

Muon system layout:

- *Barrel*: 12+2 layers in yoke
- *Endcap*: 5+2 layers
- *Muon Filter*: 4 layers
- *Forward Range System*:
  - 16+2 layers
  - Iron absorbers
- *Detectors:* Drift tubes with wire & cathode strip readout



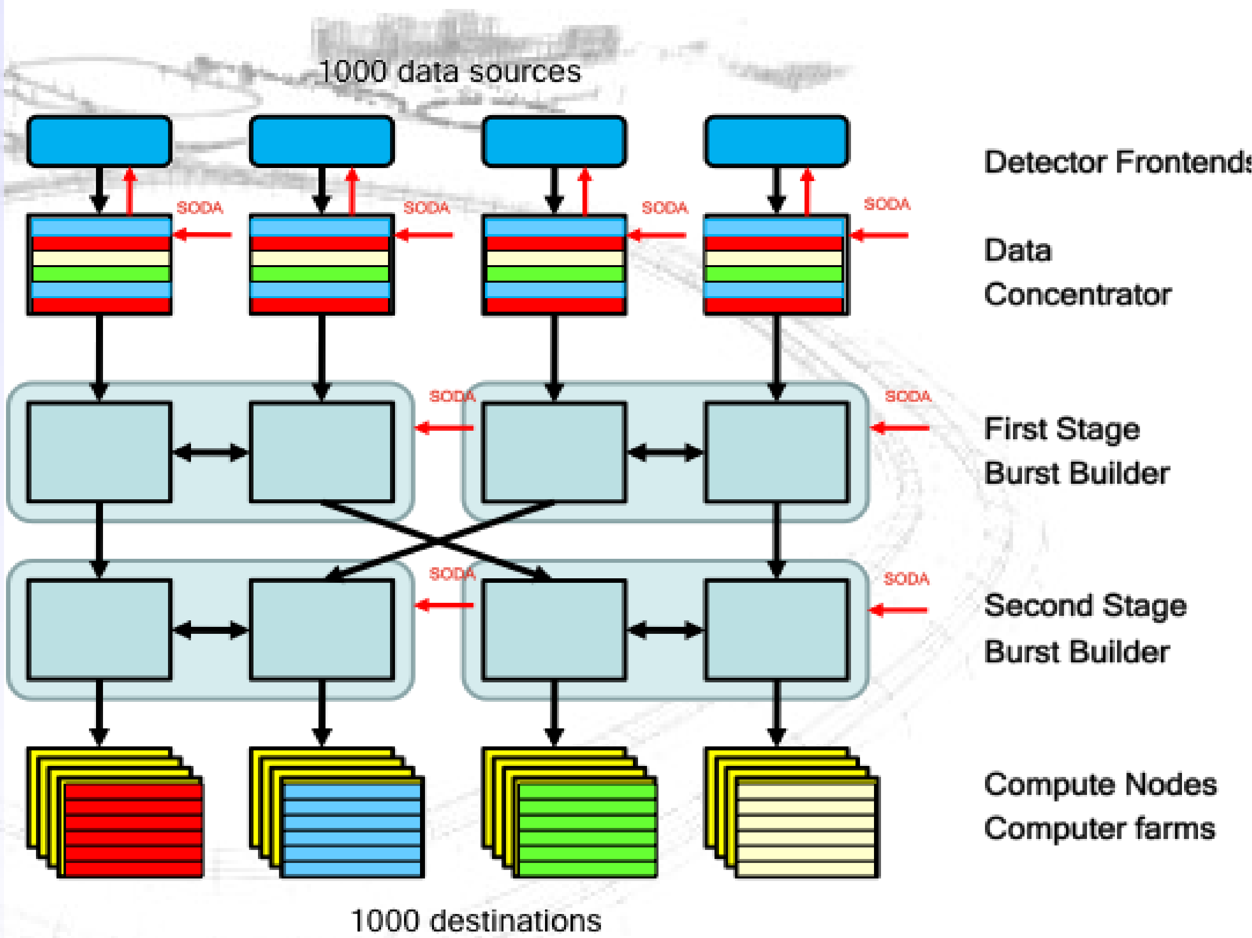


P̄ANDA Data Acquisition

Self triggered readout

- Components:
  - Time distribution system
  - Intelligent frontends
  - Powerful compute nodes
  - High speed network
- Data Flow:
  - Data reduction
  - Local feature extraction
  - Data burst building
  - Event selection
  - Data logging after online reconstruction

➔ **Programmable Physics Machine**



Topics for Cooperation

Physics Topics

- Structure functions
  - Drell Yan process
  - Transversity
- Hadrons in Medium
  - Mass and width modifications
  - Suppression of states
- Hypernuclei

Detector Topics

- Expertise at GSI:
  - Large area APDs
  - Development of DIRCs
  - Light-weight GEM-TPC development
- Expertise at BNL:
  - Polarized beams
  - **GEM detectors**
  - ➔ *Coop on large area GEMs*
  - **Silicon vertex detectors**
  - ➔ *Coop on Readout ASICs*
  - High rate DAQ systems

Summary

BNL future developments

- High luminosity running at RHIC
- EIC: Physics of structure functions
- → New high rate setups

PANDA & FAIR start in hadron physics from 2018

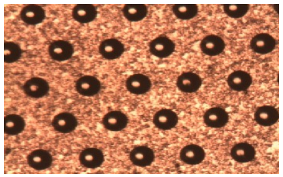
- Versatile physics machine with full detection capabilities
- PANDA will shed light on many of today's QCD puzzles
- Beyond PANDA further plans for spin physics at FAIR exist

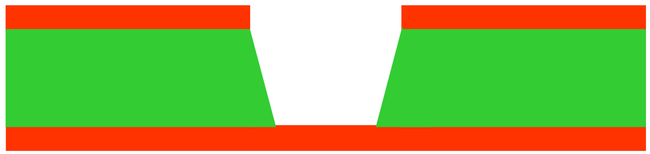
Cooperation of GSI/FAIR and BNL

- Mutual benefits for future
- Exchange of expertise
- Physics and detector topics

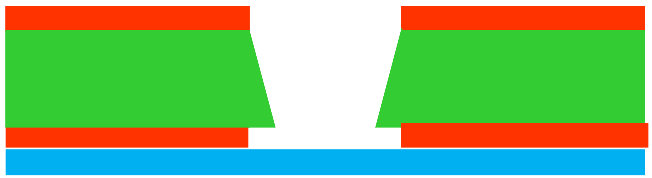
Backup Slides

Single Mask GEM

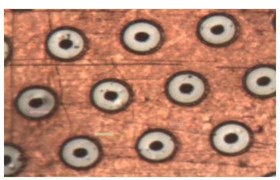


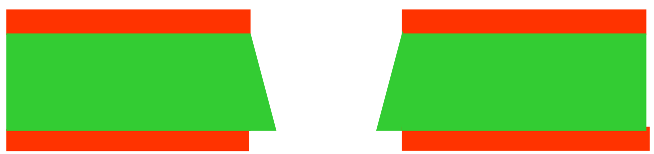


Chemical Polyimide etching

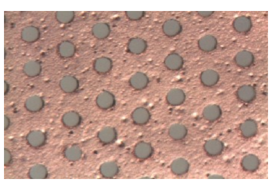


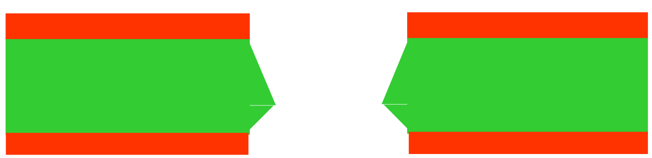
Copper electro etching



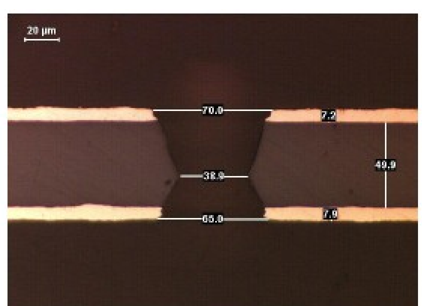


Stripping





Second Polyimide etching

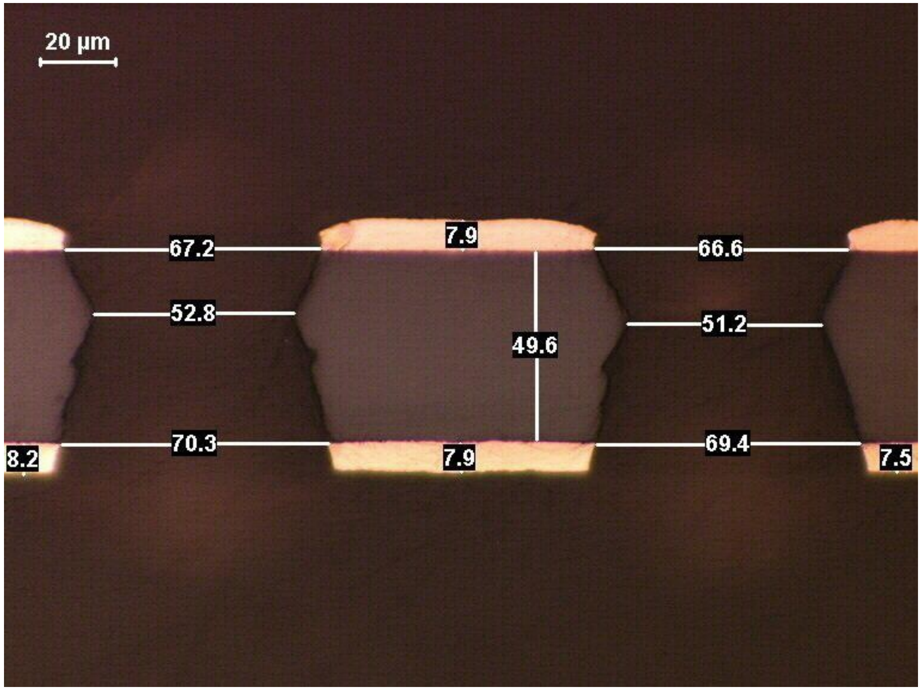


Reality

Rui Oliveira, CERN

Single Mask GEM

Single mask GEM from CERN



Double mask GEM from external company

Critical items:

- Time critical etching
- Highly homogeneous etching solution

Largest Size GEM Foils: CMS

CMS Muon Upgrade:
99 cm x 45.5cm x 22 cm
(6 pieces)